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SHOP TEST OF 10-CYLINDER DIESEL ENGINE.

BY PHILIP MALLOZZI* AND JOHN F. FOX†.

The need of sufficient data to enable the brake horsepower developed in a Diesel engine to be determined directly from the indicated horsepower, that is, from a set of indicator cards, has often been felt. In addition, an accurate knowledge of the distribution of the I.H.P. used in driving the attached pumps and air compressors, and used in friction and scavenging in the engine proper, considered apart from air compressors and attached auxiliaries is very valuable and necessary when considering engines from the design standpoint.

To obtain usable data, extensive tests on an ex-German engine have been conducted by the New York Navy Yard and the information collated thereby has been recorded for future use.

Machinery construction for shipboard generally has included, besides the engine proper, the manufacture of the attached auxiliaries, lubricating oil and circulating water pumps.

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In the tests here listed many auxiliaries of this nature have been tested independently by driving them with temporary electric motors consequently much data relative to the power consumed has been obtained. With this information available, it has become possible to determine with more than usual accuracy, not only the actual ratio of B.H.P. to I.H.P. but also the efficiency of the engine considered as consisting of working cylinders alone without air compressor or attached auxiliaries.

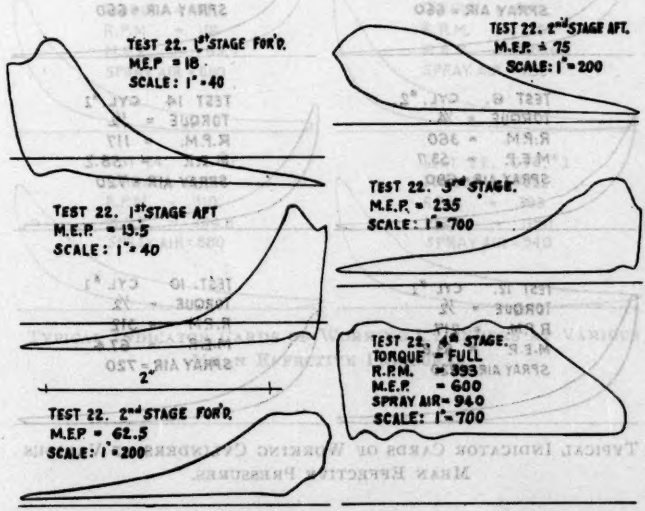
To obtain data for a series of curves giving the ratio of B.H.P. to I.H.P., efficiency and fuel consumption at all speeds and loads, it was decided to run a series of thirty-five tests, see Plate A, and to take complete sets of indicator cards from both air compressor and working cylinders, at the same time noting fuel consumption and brake horsepower.

In order to reduce as much as possible the time consumed in running these tests, and yet obtain accurate data on fuel consumption, the fuel was supplied from a long and relatively slender tubular stand pipe. This stand pipe was fitted with a long gauge glass, and when filled to the top contained just enough fuel to run the engine for twenty minutes. The gauge glass was fitted with a scale, accurately calibrated in pounds of fuel, and it was found possible, by the use of a stop watch, to accurately time the interval required to consume a definite quantity of fuel and hence obtain the fuel consumption without running the engine for an excessive length of time. The arrangement is shown on Plate C. During each run a complete set of indicator cards was taken and the load on the dynamometer noted.

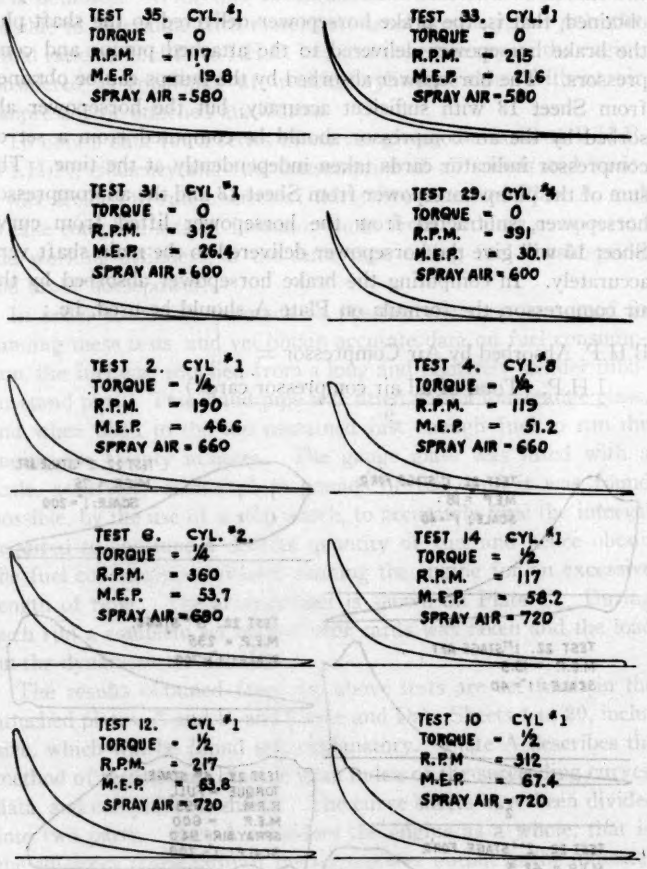
The results obtained from the above tests are set forth in the attached plates, A and B, and Curve and Data Sheets 1 to 20, inclusive, which will be found self-explanatory. Plate A describes the method of testing and Plate B is an index of the succeeding curves, data, and computation sheets. The curve sheets have been divided into two parts. Part A considers the engine as a whole, that is, the efficiency is the ratio of the horsepower output to the indicated horsepower, and the power absorbed by air compressors and pumps is charged against the efficiency of the engine. Part B considers the engine alone and credits the engine with horsepower absorbed by the attached pumps and air compressor.

For ordinary use, to determine the brake horsepower, given the indicated horsepower, the curves on Sheet 3 may be used. For more accurate work the curves on Sheet 15 should be used. From the curves on Sheet 15 the total brake horsepower output may be obtained, that is, the brake horsepower delivered to the shaft plus the brake horsepower delivered to the attached pumps and compressors. The horsepower absorbed by the pumps can be obtained from Sheet 13 with sufficient accuracy, but the horsepower absorbed by the air compressor should be computed from a set of compressor indicator cards taken independently at the time. The sum of the pump horsepower from Sheet 13 and the air compressor horsepower, subtracted from the horsepower lifted from curve Sheet 15 will give the horsepower delivered to the main shaft very accurately. In computing the brake horsepower absorbed by the air compressor, the formula on Plate A should be used, i.e.:

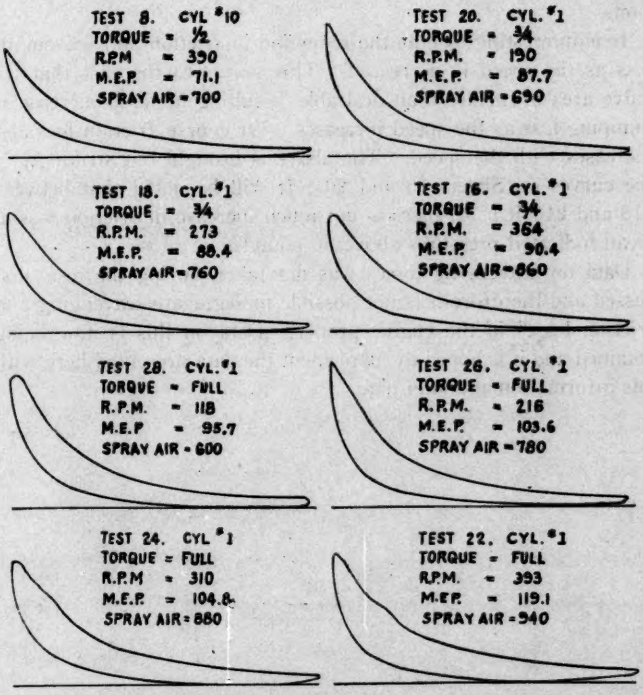
$$\text{B.H.P. Absorbed by Air Compressor} = \frac{\text{I.H.P. (Total of all air compressor cards)}}{.9}$$



COMPLETE SET OF AIR COMPRESSOR INDICATOR CARDS TAKEN AT ENGINE OVERLOAD TEST—2677.1 B.H.P.—393 R.P.M.



TYPICAL INDICATOR CARDS OF WORKING CYLINDERS AT VARIOUS MEAN EFFECTIVE PRESSURES.



TYPICAL INDICATOR CARDS OF WORKING CYLINDERS AT VARIOUS MEAN EFFECTIVE PRESSURES.

Considering the curves on Sheet 16, it will be noted that the B.H.P., is the total B.H.P. delivered to the main shaft plus the B.H.P. absorbed in driving the air compressor and pumps. The loss in friction and scavenging or air pumping in the engine alone is given by the vertical distance between the dot and dash 45-degree line and any particular point on one of the curves under consideration.

It is interesting to note the reduction in friction and scavenging loss as the speed is decreased. This points to the fact that the valve area is smaller than desirable, resulting in rapid increase in pumping loss as the speed increases. Of course friction loss also increases with the speed. The above is brought out strikingly in the curves on Sheets 10 and 20. It will be noted that between 118 and 216 R.P.M. there is not much increase in friction loss at mean indicated pressures above 50 pounds.

Data on scavenging losses was not taken during the tests discussed and therefore it is not possible to segregate scavenging and friction losses in the engine proper. Data on this is now being obtained and it is hoped to supplement the data presented here with this information at a later date.

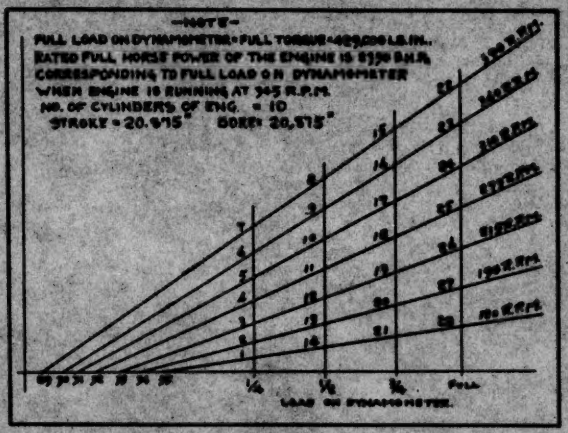
SHOP TESTS OF A 10 CYL. 4 CYCLE DIESEL ENGINE
RATED LOAD = 2350 B.H.P. AT 345 R.P.M.

① OBJECT OF TESTS

TO DETERMINE THE EFFICIENCY AND FUEL CONSUMPTION OF THE ENGINE AT ALL LOADS AND SPEEDS.

② METHOD OF TEST AND PREPARATION FOR TESTS.

THE ENGINE WAS ATTACHED TO A FROUDE DYNAMOMETER THRU A LINE SHAFT SECURED TO THE ENGINE FLYWHEEL. THIRTY-FIVE TESTS WERE MADE AT VARIOUS SPEEDS AND POWERS AS INDICATED BELOW.


—NOTE—
FULL LOAD ON DYNAMOMETER = FULL TORQUE = 422,000 LB.-IN.,
RATED FULL HORSE POWER OF THE ENGINE IS 2350 B.H.P.
CORRESPONDING TO FULL LOAD ON DYNAMOMETER
WHEN ENGINE IS RUNNING AT 345 R.P.M.
NO. OF CYLINDERS OF ENG. = 10
STROKE = 20.875" BORE = 20.875"
LOAD ON DYNAMOMETER.

FOUR WEIGHTS WERE USED ON THE DYNAMOMETER CORRESPONDING TO 25-50-75 & 100% OF FULL LOAD TORQUE. SEVEN TESTS WERE TAKEN AT EACH TORQUE AND SEVEN WITH DYNAMOMETER UNLOADED. THE RANGE OF SPEEDS USED WAS 150 TO 390 R.P.M. THE NUMERALS ON THE ABOVE SKETCH INDICATE THE NUMBER AND ORDER IN WHICH THE TESTS WERE TAKEN.

③ DATA TAKEN DURING TESTS.

FOR EACH TEST, THE FUEL CONSUMPTION, INDICATOR CARDS FROM THE WORKING CYLINDERS AND THE AIR COMPRESSOR, AND THE REVOLUTIONS PER MINUTE AS DETERMINED FROM COUNTER READINGS AT THE BEGINNING AND END OF EACH TEST, WERE TAKEN SIMULTANEOUSLY. THE COMBINED EXHAUST TEMPERATURES OF THE ENGINE WORKING CYLINDERS AND THE AIR PRESSURES IN ALL THE STAGES OF THE AIR COMPRESSOR WERE ALSO TAKEN. SEE SHEETS 1 & 2.

④ COMPUTATIONS.

INDICATOR CARDS OF THE ENGINE WORKING CYLINDERS WERE ENLARGED TO THREE TIMES THEIR LINEAR DIMENSIONS BY PHOTOSTATING, THUS GIVING NINE TIMES THE AREA. A LARGE ROLLING PLANIMETER WAS USED TO OBTAIN THE I.H.P. FROM THE CARDS. COMPUTATIONS WERE MADE TO DETERMINE THE FUEL CONSUMPTION PER B.H.P. AND EFFICIENCY WITH POWER ABSORBED BY THE AIR COMPRESSOR AS PART OF THE MECHANICAL LOSSES.- (CONSIDERATION A - OVERALL CONSIDERATION), AND WITH POWER ABSORBED BY THE AIR COMPRESSOR AND PUMPS ELIMINATED— (CONSIDERATION B - ENGINE CONSIDERED ALONE.)

A) OVERALL CONSIDERATION

THIS CONSIDERATION INCLUDES SHEETS 1 TO 12 INCLUSIVE. COMPUTATIONS UNDER CONSIDERATION A ARE BASED ON THE B.H.P. OUTPUT BEING THAT BALANCED BY THE DYNAMOMETER. THEREFORE THE MECHANICAL EFFICIENCY UNDER THIS CONSIDERATION IS:-

$$\text{MECH. EFFICIENCY} = \frac{\text{B.H.P. DUE TO WEIGHT ON DYNAMOMETER}}{\text{I.H.P. FROM ENGINE WORKING CYLINDERS}}$$

B) ENGINE CONSIDERED ALONE

THIS CONSIDERATION INCLUDES SHEETS 13 TO 20 INCLUSIVE. COMPUTATIONS UNDER THIS CONSIDERATION ARE BASED ON THE B.H.P. OUTPUT BEING THAT BALANCED BY THE DYNAMOMETER PLUS THE POWER ABSORBED BY THE AIR COMPRESSOR AND ATTACHED PUMPS. THEREFORE THE MECHANICAL EFFICIENCY UNDER THIS CONSIDERATION IS:-

$$\text{MECH. EFF.} = \frac{\text{B.H.P. DUE TO WEIGHT ON DYNAMOMETER} + \text{B.H.P. ABSORBED BY AIR COMPRESSOR} + \text{B.H.P. ABSORBED BY PUMPS}}{\text{I.H.P. FROM ENGINE CYLINDER CARDS.}}$$

THIS GIVES THE ACTUAL PERFORMANCE OF THE ENGINE CONSIDERED APART FROM ITS ATTACHED AUXILLIARIES. THE POWER ABSORBED BY THE AIR COMPRESSOR IS ARRIVED AT UPON THE ASSUMPTION THAT THE MECHANICAL EFFICIENCY OF THE AIR COMPRESSOR IS 90%. ON THIS ASSUMPTION WE OBTAIN:-

$$\text{B.H.P. ABSORBED BY AIR COMP.} = \frac{\text{I.H.P. TOTAL OF ALL AIR COMP. STAGES FROM AIR COMP. INDICATOR CARDS}}{9}$$

THE POWER ABSORBED BY THE ATTACHED LUBRICATING AND CIRCULATING WATER PUMPS IS BASED ON SHOP TESTS OF SIMILAR PUMPS DRIVEN BY ELECTRIC MOTORS AT APPROXIMATELY THE SAME SPEEDS WITH APPROXIMATELY THE SAME DELIVERY PRESSURES AND RATES OF FLOWS.

⑤ RESULTS.

CURVES HAVE BEEN DRAWN FROM THE DATA COVERED BY SHEETS 1 & 2 & 15 & 16. IT IS BELIEVED THEY WILL BE FOUND SELF-EXPLANATORY. APPARENTLY THE BEST PERFORMANCE FROM THE STANDPOINT OF EFFICIENCY WAS OBTAINED WHEN THE ENGINE RAN AT 118 AND 189 R.P.M. WITH FULL LOAD TORQUE. SEE NOTE ON SKETCH.

TEST CONDUCTED & REPORT BY Miles Mallory Technical Aide J.E. Jos M.E.

CHECKED & IN CHARGE OF WORK J.E. Jos Mech. Eng.

Plate A

INDEX TO SHEETS OF CURVES AND COMPUTATIONS SHOWING RESULTS OF ALL TESTS.

(A) OVERALL CONSIDERATION PARAGRAPH (4)

SHEETS FROM 1 TO 8 INCLUSIVE

—— CONTENTS ——

	SHEET No.
COMPUTATIONS IN THE ORDER OF VARYING TORQUE CONSTANT R.P.M.	1
" " " " " CONSTANT " VARYING "	2
B.H.P.–M.I.P. CURVES OF VARYING TORQUE CONSTANT R.P.M.	3
I.H.P.–B.H.P. " " " " "	4
MECH. EFF.–M.I.P. " " " " "	5
FUEL CONSUMPTION–M.I.P. CURVES OF VARYING TORQUE CONSTANT R.P.M.–FOR 118 & 180 R.P.M.	6
" " " " " " " " " " " 216 & 252 "	7
" " " " " " " " " " " 318, 366 & 392 "	8
THERMAL EFF.–M.I.P. CURVES OF VARYING TORQUE CONSTANT R.P.M.	9
COMPARISON CURVES OF THERM. EFF. AND FUEL CONSUMPTION	10
FUEL IN LBS/HOUR–R.P.M. CURVES OF CONSTANT TORQUE VARYING R.P.M.	11
AVERAGE EXH. TEMP.–" " " " " "	12

(B) ENGINE ALONE CONSIDERATION PARAGRAPH (4)

SHEETS FROM 13 TO 20 INCLUSIVE

—— CONTENTS ——

	SHEET No.
COMPUTATIONS IN THE ORDER OF VARYING TORQUE CONSTANT R.P.M.	13
" " " " " CONSTANT " VARYING "	14
B.H.P.–M.I.P. CURVES OF VARYING TORQUE CONSTANT R.P.M.	15
I.H.P.–B.H.P. " " " " "	16
MECH. EFF.–M.I.P. " " " " "	17
FUEL CONSUMPTION–M.I.P. " " " " "	18
THERMAL EFF.–M.I.P. " " " " "	19
COMPARISON CURVES OF FUEL CONSUMPTION AND THERMAL EFFICIENCY	20

FUEL MEASURING DEVICE FOR SHORT TESTS C

INDICATOR CARDS OF ENGINE AND AIR COMPRESSOR OF ALL TESTS ..... B1 TO B5

LIST OF SYMBOLS

$(B.H.P)_o$	= BRAKE HORSE POWER OUTPUT DUE TO WEIGHT ON DYNAMOMETER	CONSIDERATION–A
$(M.E)_a$	= OVERALL MECHANICAL EFFICIENCY	" –A
$(T.E)_a$	= THERMAL EFFICIENCY (B.H.P.)$_a$ BASIS	" –A
$(B.H.P)_b$	= BRAKE HORSE POWER OUTPUT DUE TO WEIGHT ON DYNAMOMETER PLUS THE POWER ABSORBED BY AIR COMPRESSOR AND ATTACHED WATER & OIL PUMPS	" –B
$(M.E)_b$	= MECHANICAL EFFICIENCY OF ENGINE APART FROM THE AIR COMPRESSOR AND ATTACHED WATER & OIL PUMPS	" –B
$(T.E)_b$	= THERMAL EFFICIENCY (B.H.P.)$_b$ BASIS	" –B
(I.H.P)	= INDICATED HORSE POWER FROM ENGINE CYLINDER CARDS	" A & B
(M.I.P)	= MEAN INDICATED PRESSURE FROM ENGINE CYLINDER CARDS	" A & B
(T.E)$_i$	= THERMAL EFFICIENCY (I.H.P.) BASIS	" A & B

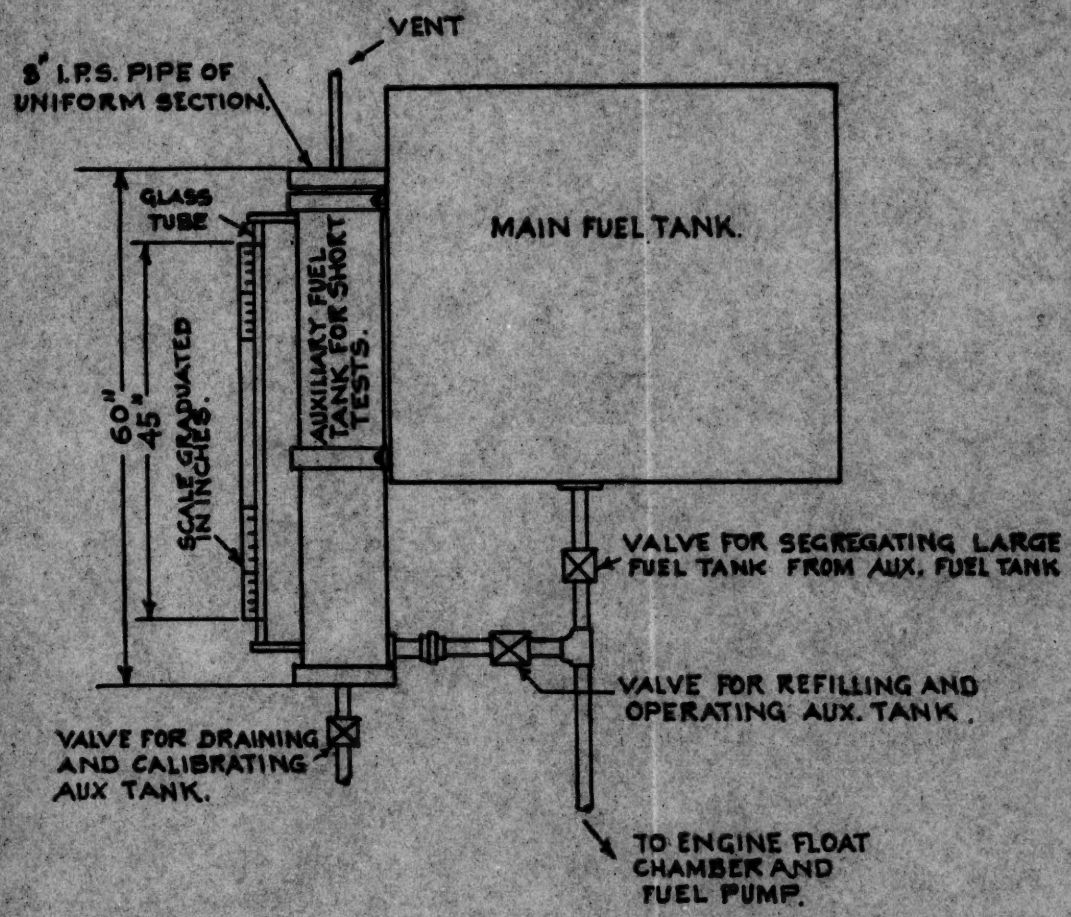
DESCRIPTION OF FUEL USED

DIESEL ENGINE GAS OIL FROM THE GULF REFINING CO.

SPECIFIC GRAVITY AT 60°F	0.8564 (34.6° B.)
FLASH POINT (PENSKY-MARTENS)	181°F.
VISCOSITY AT 32°F. (SAYBOLT-UNIVERSAL)	47 SECONDS
SULPHUR	.35%
CALORIFIC VALUE PER LB.	18,532 B.T.U.

PLATE B

FUEL MEASURING DEVICE USED ON ALL TESTS


VENT
8" I.P.S. PIPE OF UNIFORM SECTION.
GLASS TUBE
MAIN FUEL TANK.
AUXILIARY FUEL TANK FOR SHORT TESTS.
60"
45"
SCALE GRADUATED IN INCHES.
VALVE FOR SEGREGATING LARGE FUEL TANK FROM AUX. FUEL TANK
VALVE FOR REFILLING AND OPERATING AUX. TANK.
VALVE FOR DRAINING AND CALIBRATING AUX TANK.
TO ENGINE FLOAT CHAMBER AND FUEL PUMP.

A COLUMN OF FUEL 45" HIGH IS USED, THE INTERVAL OF TIME IS REGISTERED WITH A STOP WATCH.
ABOUT FIVE MINUTES AT FULL POWER TO ABOUT 20 MINUTES AT NO LOAD IS THE TIME REQUIRED BY THE ENGINE TO CONSUME SAID COLUMN OF FUEL.

Plate C

		ENGINE					AIR COMPRESSORS									FUEL CONSUMED			AIR COMPRESSOR GAGE PRESSURE LBS./SQ.IN.						
HYDRO TEST	LOAD ON DYN.	R.P.M.	B.H.P.	M.E.P.	I.H.P.	SPEED REG.	1ST STAGE		2ND STAGE		3RD STAGE		4TH STAGE		DEVELOPED AIR COMPR.		LBS. PER B.H.P. HOUR	LBS. PER I.H.P. HOUR		1ST	2ND	3RD	4TH	AIR MAIN		
							M.E.P.	I.H.P.	M.E.P.	I.H.P.	M.E.P.	I.H.P.	M.E.P.	I.H.P.	I.H.P.	% ENGINE										
35	0	117	0	19.3	203.7	0					150	18.6	350	8.9	66.9	33	60.8	.2984		16	100	410	775	580	196	0
1	¼	119	202.7	42.8	453.4	441					215	22.2	500	7.0	92.4	21	128.6	.2799	.6344	34	160	640	800	600	215	20.4
14	½	117	398.5	64.4	679.7	586					275	28.0	125	3.2	110.1	16	185.7	.2732	.4659	40	180	700	725	720	295	27.0
21	¾	117	592.8	82.2	867.6	683					250	25.4	100	2.6	103.8	12	258.8	.2992	.4929	40	165	670	625	625	405	29.9
28	FULL	118	803.8	100.3	1062.6	752					280	28.8	290	7.4	118.7	11.1	336.7	.3144	.4176	44	200	740	925	710	585	31.0
34	0	187	0	20.5	345.8	0					135	22.0	490	19.8	92.5	27	100.4	.2903		9	80	340	800	560	155	0
2	¼	190	323.6	43.7	749.0	432					210	34.7	510	21.5	147.1	19.6	207.7	.2773	.6418	24	120	560	1150	660	255	20.2
13	½	190	647.1	65.2	1117.5	579					260	42.9	340	14.0	162.0	14.4	302.5	.2706	.4674	30	150	620	900	710	345	27.7
20	¾	190	970.7	84.5	1448.3	670					225	37.2	240	9.9	153.6	10.6	408.6	.2900	.4178	30	145	800	750	690	470	31.0
27	FULL	189	1287.5	103.8	1769.7	727					275	45.2	465	19.1	185.6	10.5	533	.3011	.4139	36	160	680	1025	740	595	31.9
33	0	215	0	21.5	416.9	0					135	26.2	855	25.9	108.5	26	115.8	.2777		8	80	320	1200	580	170	0
8	¼	217	362.6	43.9	853.3	430					215	40.8	670	31.6	168.0	19.8	257.2	.2760	.6417	22	120	540	1550	690	265	20.2
12	½	217	739.1	67.6	1323.3	558					240	48.3	390	18.4	182.2	13.8	447.6	.2676	.4708	28	135	600	900	720	370	27.6
19	¾	217	1108.7	83.6	1636.6	677					235	44.4	385	18.2	171.5	10.4	470	.2871	.4239	28	140	560	900	700	500	30.6
26	FULL	216	1471.4	103.6	2018.7	728					285	53.5	590	22.7	211.4	10.4	613	.3036	.4166	32	155	660	1250	780	630	31.1
32	0	275	0	23.8	530.4	0					125	29.9	590	35.2	138.0	26.1	159.8	.2786		4	58	285	1250	600	195	0
4	¼	277	471.7	46.3	1186.9	407					150	36.2	635	38.2	164.1	14.1	367.8	.2660	.6825	10	80	320	1000	640	310	19.9
11	½	280	963.7	69.1	1745.4	546					245	53.6	390	23.7	292.7	12	470.1	.2693	.4929	18	110	440	750	780	435	24.3
18	¼	273	1394.8	85.9	2115.6	685					225	53.4	560	29.6	318.7	10.1	661.2	.2870	.4988	23	130	500	1000	760	575	29.9
25	FULL	276	1888.1	106.6	2654.3	708					270	64.8	640	38.4	258.8	9.7	816.9	.3025	.4889	30	140	580	1300	840	725	29.8
31	0	312	0	24.2	691.1	0					115	34.2	575	59.0	184.4	19.7	195.8	.2894		2	50	280	1250	600	225	0
5	¼	314	534.7	48.4	1370.9	390					140	38.2	515	36.2	180.9	11.7	388.3	.2612	.6699	10	70	310	1000	660	340	19.3
10	½	312	1062.7	67.1	1888.5	562					200	54.2	610	41.4	226.8	11.9	522.9	.2761	.4920	18	100	420	1100	720	455	24.3
17	¾	310	1583.8	86.2	2410.6	657					215	58.0	540	36.8	289.9	9.8	798.6	.2939	.4974	23	120	450	1025	800	620	29.0
24	FULL	310	2111.7	106.3	2972.6	710					250	67.4	610	41.1	328.6	9.4	947.7	.3188	.4487	30	130	520	1100	880	785	28.9
30	0	360	0	28.6	831.3	0					120	37.6	566	44.2	199.4	17.9	244.3	.2938		2	45	230	1150	710	265	0
6	¼	364	619.9	51.3	1684.5	368					140	44.4	575	41.5	190.4	11.3	449.4	.2669	.7249	8	85	320	1000	680	410	17.9
9	½	363	1236.4	70.1	2295.6	538					185	58.4	815	40.6	357.4	10.3	648.3	.2811	.5219	16	95	360	925	780	550	24.8
16	¼	364	1899.7	88.9	2919.1	637					210	66.5	590	46.6	369.4	9.1	888.5	.3043	.4777	22	110	420	1100	860	715	27.1
23	FULL	363	2472.8	109.1	3571.6	692					235	74.1	600	47.4	393.7	8.5	1148	.3213	.4642	26	130	480	1025	910	785	27.9
29	0	391	0	28.5	1005.2	0					100	34.0	550	46.7	247.2	14.6	287.1	.2956		18	40	225	1100	600	270	0
7	¼	391	645.9	49.5	1745.9	381					150	51.0	625	53.1	314.8	12.1	504.4	.2891	.7874	10	80	305	1100	680	430	17.1
8	½	390	1328.3	67.8	2386.3	556					140	47.5	465	39.4	253	8.0	738.5	.3096	.5569	10	80	295	750	700	605	23.3
15	¾	398	2007.8	89.6	3176.5	632					215	73.5	710	60.6	292.2	9.4	1014	.3192	.5050	20	110	420	1300	840	795	25.7
22	FULL	393	2677.1	111.7	3960.0	676					235	80.2	600	51.3	328.5	8.1	1316	.3323	.4915	24	120	460	1000	940	1030	26.4

COMPUTATIONS ON THIS SHEET ARE IN THE ORDER OF VARYING ENGINE CONSTANT R.P.M.

NOTE

(A) Overall Consideration

B.H.P. WT. = B.H.P. DO TO WEIGHT ON DYNAMOMETER

SHEET (1)

* For Thermal Eff. I.H.P. Basis See Sheet 1304

		ENGINE					REVERSED AIR COMPRESSORS									FUEL CONSUMED			AIR COMPRESSORS GAGE PRESSURES LBS/SQ IN						
							1st STAGE		2nd STAGE		3rd STAGE		4th STAGE												
TYPE OF TEST	LOAD ON DYN.	R.P.M.	S.H.P.	M.E.P.	I.H.P.	SLIP %	M.E.P.	I.H.P.	M.E.P.	I.H.P.	M.E.P.	I.H.P.	M.E.P.	I.H.P.	I.H.P.	% COMP.	LBS/HOUR	LBS/I.H.P. HOUR	LBS/GAL	1st STAGE	2nd STAGE	3rd STAGE	4th STAGE	AIR DEL.		
85	0	117	0	19.3	203.7	0	P-1.5 / A-1.5	13.3 / 8.3	P-42.5 / A-30	9.1 / 10.7	160	15.6	350	8.9	466.9	33	60.8	.2944		16	100	410	775	880	130	0
34	0	187	0	20.5	345.8	0	P-25 / A-25	13.5 / 9.7	P-31.5 / A-42.5	12.9 / 14.6	135	22.0	490	19.8	92.5	37	100.4	.2903		9	80	340	1000	860	155	0
33	0	215	0	21.5	416.9	0	P-35 / A-35	18.8 / 11.4	P-35 / A-42.5	13.8 / 16.7	135	25.2	555	25.9	106.5	36	115.8	.2777		8	80	330	1200	980	170	0
32	0	275	0	23.8	590.4	0	P-50 / A-50	14.6 / 10.5	P-50 / A-32	18.1 / 19.7	135	29.9	690	35.2	125.0	24.1	139.8	.2786		4	58	285	1150	600	195	0
31	0	312	0	24.2	681.1	0	P-70 / A-55	14.6 / 11.3	P-62.5 / A-36	18.7 / 20.0	115	31.2	575	33.0	134.4	19.7	198.8	.2874		2	50	280	1250	600	225	0
30	0	360	0	25.6	831.3	0	P-85 / A-63	18.1 / 11.8	P-82.5 / A-45	21.5 / 16.5	120	37.6	565	44.2	149.4	17.9	244.3	.2938		2	45	230	1180	710	266	0
29	0	391	0	28.5	1005.2	0	P-95 / A-65	17.8 / 12.2	P-215 / A-125	16.8 / 18.7	100	34.0	550	46.7	147.2	14.6	287.1	.2856		18	40	225	1200	600	270	0
1	½	119	202.7	42.8	459.4	44.1	P-22 / A-20	10.8 / 16.5	P-10 / A-75	15.0 / 15.8	215	22.2	390	7.8	97.4	2.1	128.6	.2395	.6344	34	160	640	800	600	215	20.4
2	½	190	323.6	43.7	743.0	43.2	P-35 / A-30	12.3 / 21.3	P-55 / A-125	14.3 / 23.5	210	34.7	510	31.5	147.1	19.6	207.7	.2773	.6418	24	120	560	1450	660	255	20.2
3	½	217	369.6	43.9	853.3	43.0	P-45 / A-45	12.5 / 21.8	P-85 / A-65	21.9 / 25.9	215	40.5	670	31.6	168.0	19.5	237.2	.2768	.6417	22	120	840	1550	680	265	20.2
4	½	277	471.7	46.3	1156.9	40.7	P-70 / A-11	14.0 / 24.1	P-437 / A-58	22.2 / 26.4	190	36.2	635	38.2	164.1	14.1	307.8	.2885	.6525	10	80	320	1000	660	310	19.9
5	½	314	534.7	48.4	1370.9	39.0	P-8 / A-9	10.1 / 19.6	P-40 / A-45	23.0 / 25.9	140	38.2	515	35.2	160.9	11.7	358.2	.2612	.6699	10	70	310	1000	660	340	19.3
6	½	364	619.9	51.3	1684.5	36.9	P-95 / A-35	12.3 / 18.9	P-45 / A-50	24.0 / 33.4	140	44.4	525	41.5	190.4	11.3	449.4	.2681	.7249	8	85	320	1000	680	410	17.9
7	½	391	665.9	49.5	1746.9	38.1	P-9 / A-7	24.7 / 18.8	P-215 / A-45	24.9 / 35.2	150	51.0	625	58.1	211.8	12.1	504.4	.2888	.7574	10	80	305	1200	680	420	17.1
14	½	117	398.5	64.4	679.7	58.6	P-23 / A-23	12.6 / 13.7	P-10 / A-125	17.7 / 19.9	275	28.0	125	3.2	110.1	16.0	188.7	.2732	.4689	40	180	700	725	720	295	27.8
13	½	190	647.1	65.2	1117.5	57.9	P-21 / A-125	20.2 / 24.5	P-66 / A-80	22.7 / 27.9	260	42.9	340	14.0	162.0	14.4	302.5	.2786	.4674	30	180	620	900	710	345	27.7
12	½	217	739.1	67.6	1323.3	58.8	P-15 / A-17	31.3 / 25.6	P-17.5 / A-75	23.8 / 28.8	240	48.3	390	18.4	179.2	13.5	347.6	.2626	.4703	28	135	660	900	720	370	27.4
11	½	280	953.7	69.1	1745.4	54.6	P-18.5 / A-145	21.9 / 28.1	P-60 / A-125	30.8 / 34.6	245	53.6	390	23.7	209.7	12.0	480.1	.2693	.4929	18	110	440	780	750	435	26.3
10	½	312	1062.7	67.1	1988.5	56.2	P-18.5 / A-145	36.7 / 24.9	P-82.5 / A-125	34.0 / 38.6	200	54.2	610	41.4	225.8	11.9	522.9	.2769	.4920	18	100	420	1100	720	456	24.3
9	½	363	1236.4	70.1	2295.5	53.8	P-19 / A-19.2	28.8 / 29.4	P-60 / A-60	38.3 / 39.2	185	58.4	515	48.6	257.4	10.3	645.3	.2811	.5219	16	95	560	925	799	650	24.8
8	½	390	1328.3	67.8	2385.3	55.6	P-28 / A-25	28.2 / 29.3	P-215 / A-45	42.3 / 32.2	140	47.5	465	39.4	194.3	8.0	738.5	.3096	.5589	10	80	295	750	700	605	23.3
21	¾	117	597.8	82.2	867.6	68.9	P-26 / A-218	22.1 / 17.4	P-18 / A-20	16.1 / 13.3	280	26.4	100	2.5	109.8	12.	258.1	.2982	.4329	40	165	670	625	625	495	27.9
20	¾	190	970.7	84.5	1448.3	67.0	P-81 / A-19	30.2 / 26	P-82.5 / A-80	23.6 / 27.8	225	37.2	240	8.9	163.6	10.6	405.6	.2800	.4178	30	145	600	780	690	470	31.0
19	¾	217	1108.7	83.6	1636.5	67.7	P-110 / A-115	32.1 / 26.3	P-82.5 / A-75	25.5 / 25.6	235	44.4	385	18.2	171.5	10.4	470	.2871	.4239	28	140	560	900	700	500	30.6
18	¾	273	1394.8	85.9	2115.5	65.9	P-112 / A-85	34.2 / 30.2	P-62 / A-70	30.0 / 36.2	225	53.4	500	29.6	215.7	10.1	607.2	.2870	.4383	25	130	500	1000	760	575	27.8
17	¾	310	1583.8	86.2	2410.6	65.7	P-82.5 / A-70	30.8 / 29.0	P-82.5 / A-70	32.5 / 41.3	215	58.0	540	36.3	238.9	9.8	788.6	.2934	.4474	23	120	450	1025	800	620	27.0
16	¾	364	1859.7	88.9	2919.1	63.7	P-85 / A-75	41.4 / 32.3	P-215 / A-125	31.3 / 43.8	210	66.5	590	46.6	268.4	9.1	888.5	.3043	.4777	22	110	420	1100	860	715	27.1
15	¾	393	2007.8	89.6	3176.5	63.2	P-82.5 / A-65	46.2 / 32.6	P-85 / A-65	35.6 / 46.7	215	73.5	710	60.6	299.2	9.4	1014	.3192	.5050	20	110	420	1300	840	795	25.7
28	FULL	118	803.8	160.3	1067.6	7.52	P-22.5 / A-25	12.4 / 20.4	P-85 / A-85	12.9 / 30.6	280	28.8	290	7.4	118.7	11.1	335.7	3144	5176	44	200	740	925	710	505	31.0
27	FULL	189	1287.5	103.8	1769.7	7.27	P-82.5 / A-21	32.5 / 32.8	P-82.5 / A-90	32.6 / 31.3	275	45.3	465	19.1	186.4	10.5	533	.3011	4139	36	160	680	1025	740	595	31.3
26	FULL	216	1471.4	103.6	2018.7	7.28	P-215 / A-20	32.3 / 28.9	P-72.5 / A-125	23.3 / 24.7	285	53.5	590	27.7	211.4	10.4	613	.3036	4166	32	135	660	1250	780	630	31.1
25	FULL	276	1880.1	106.6	2594.1	7.08	P-208 / A-18	41.8 / 34.4	P-70 / A-85	38.4 / 43.0	270	64.8	640	38.4	288.8	9.7	816.3	.3075	4339	30	140	580	1300	840	725	29.8
24	FULL	310	2111.7	106.3	2972.6	7.10	P-203 / A-17	42.6 / 34.6	P-147 / A-85	39.1 / 48.4	250	67.4	610	41.1	280	9.4	947.7	.3188	4447	30	130	520	1100	880	805	28.9
23	FULL	363	2472.8	109.1	3572.6	6.92	P-182 / A-182	42.9 / 33.2	P-42.5 / A-125	41.6 / 51.6	235	74.1	600	47.4	308.7	8.5	1148	.3213	4642	26	130	480	1025	920	905	27.9
22	FULL	393	2677.1	111.7	3960	6.76	P-18 / A-nd	43.5 / 36.8	P-42.5 / A-125	48.0 / 54.1	235	80.2	600	51.3	320.9	8.1	1316	.3323	4915	24	120	460	1000	940	1030	26.4

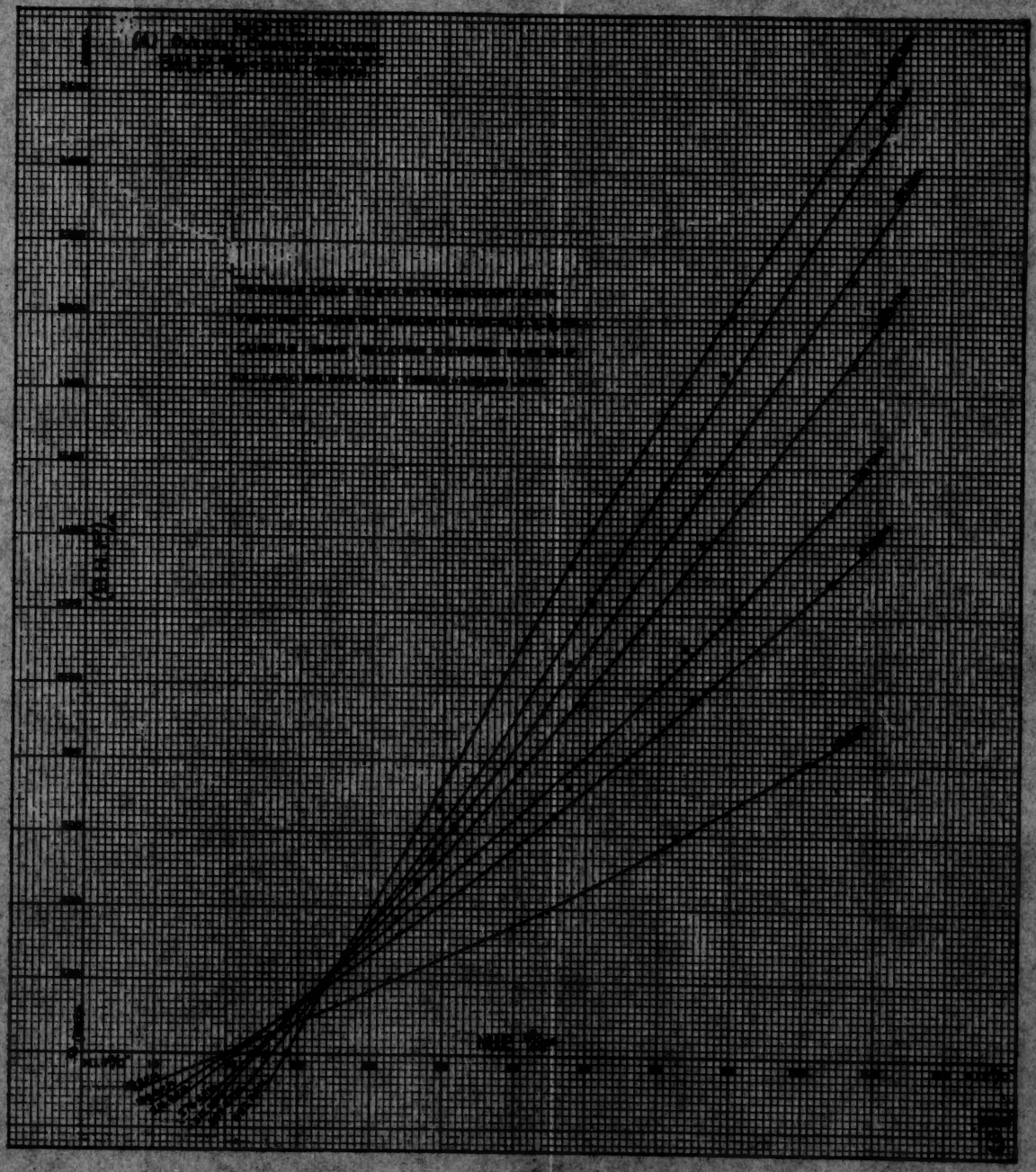
COMPUTATIONS ON THIS SHEET ARE IN THE ORDER OF CONSTANT TORQUE VARYING R.P.M.

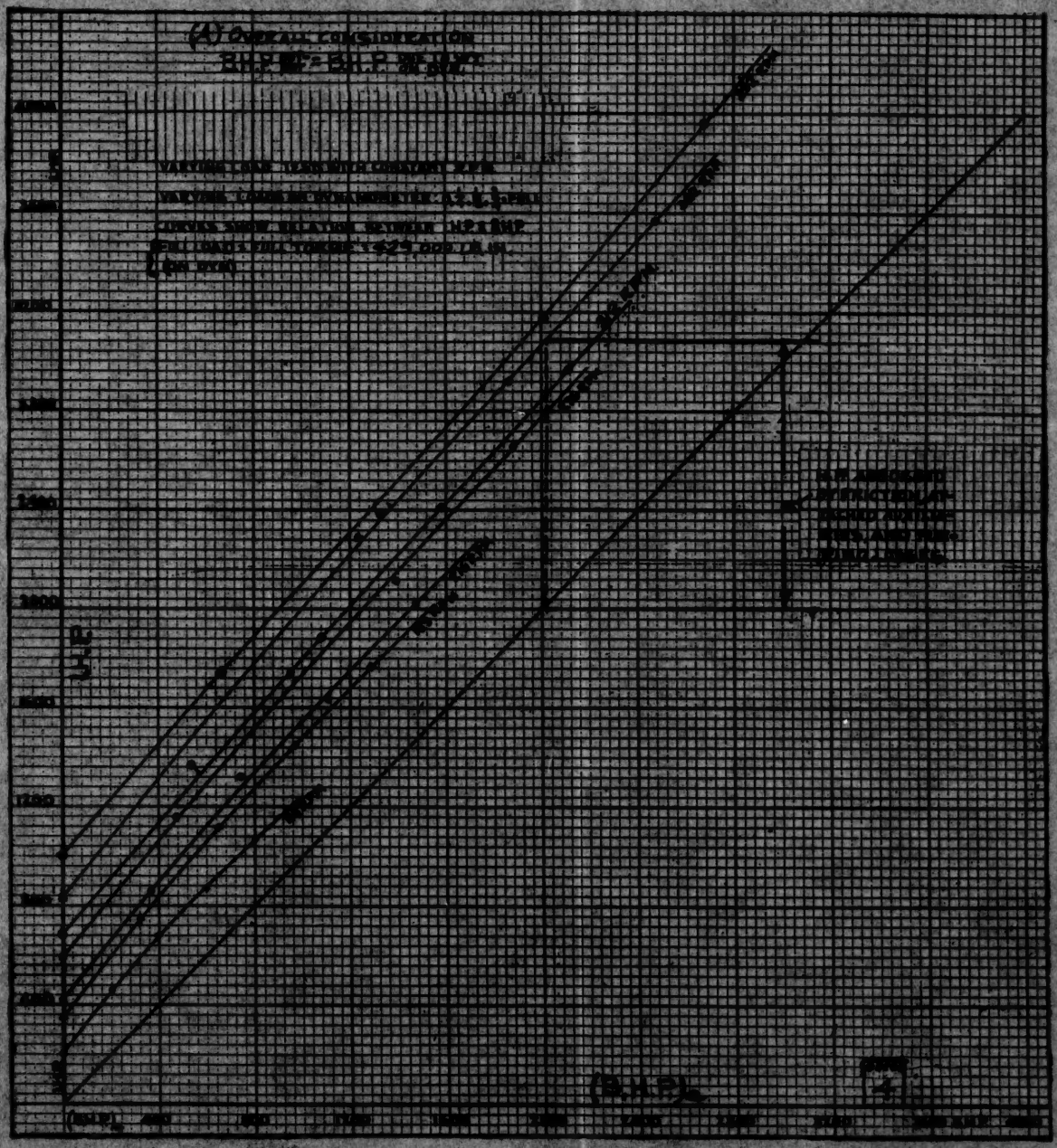
NOTE

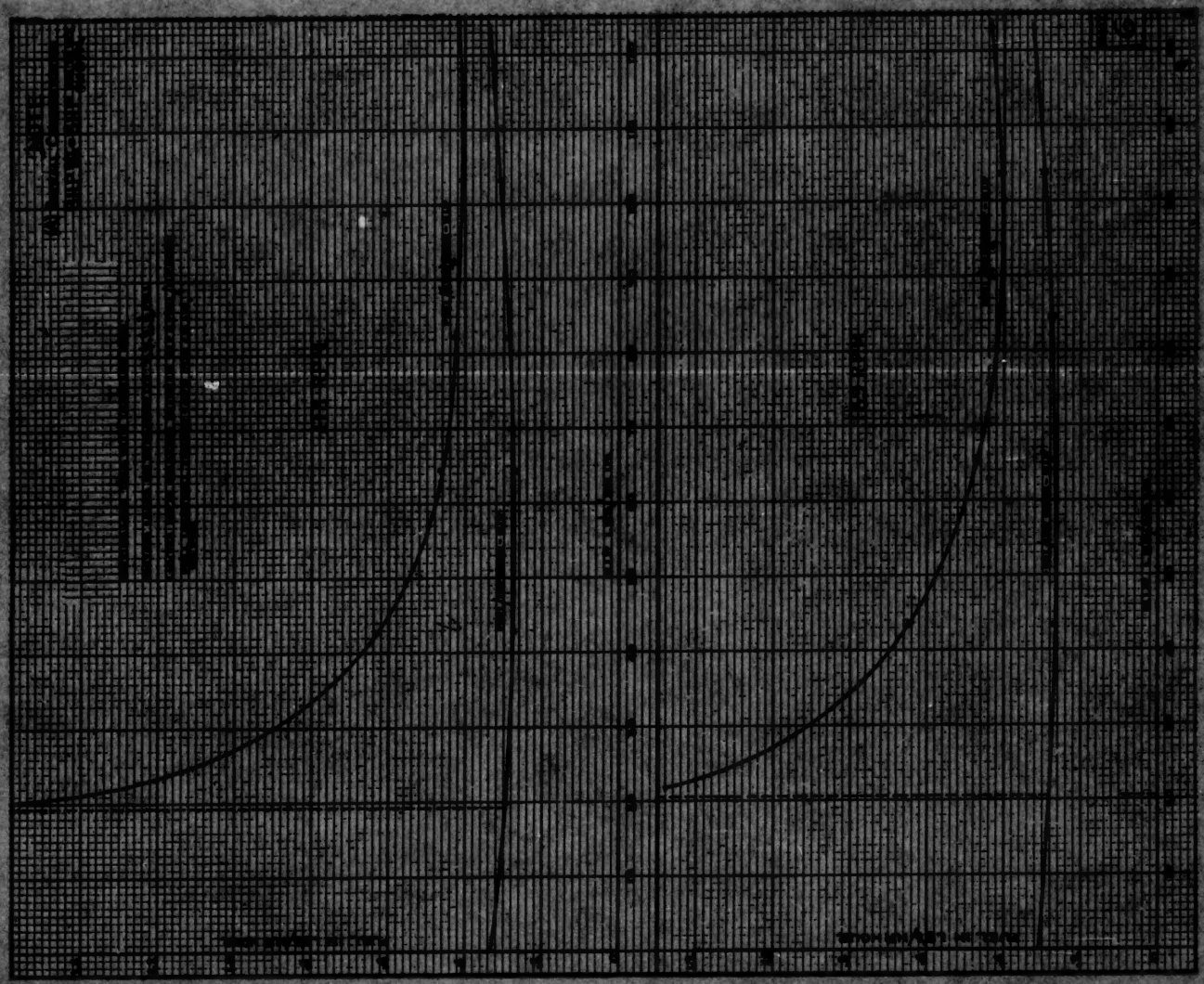
OVERALL CONSIDERATION

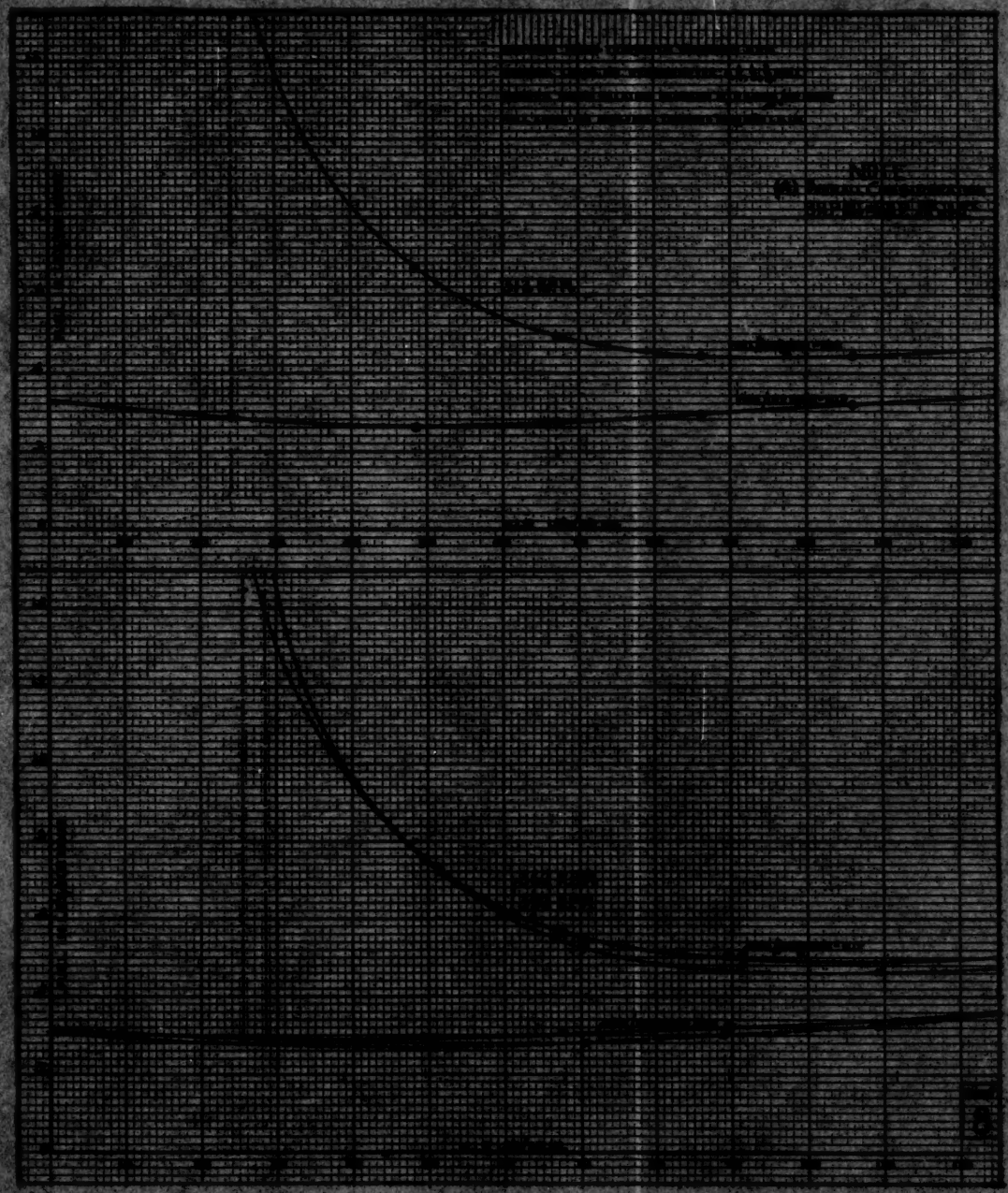
B.H.P. AT MT = B.H.P DUE TO WEIGHT ON DYNAMOMETER

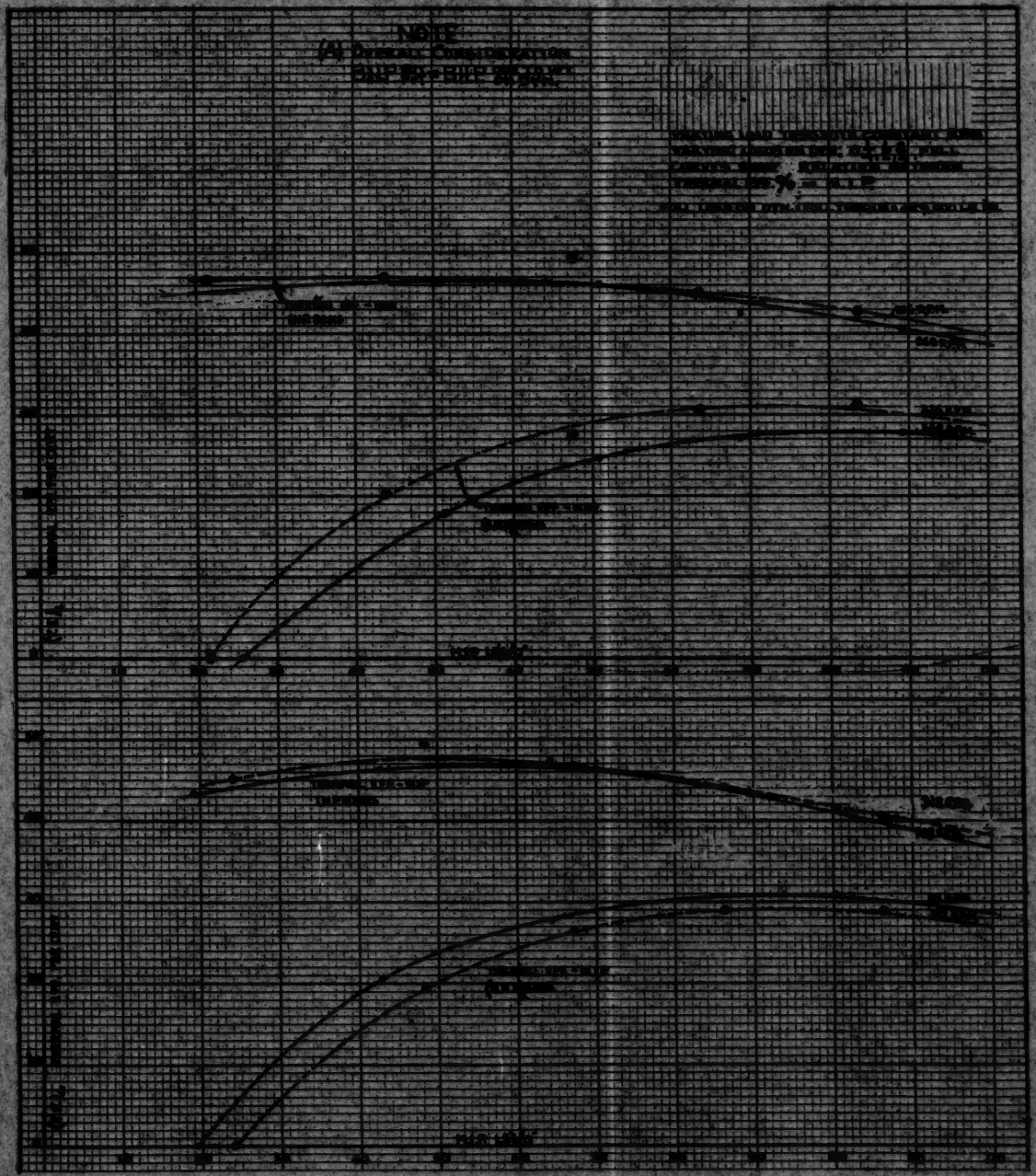
* For Ther Eff. I.H.P Basis See Sheet 13 & 14



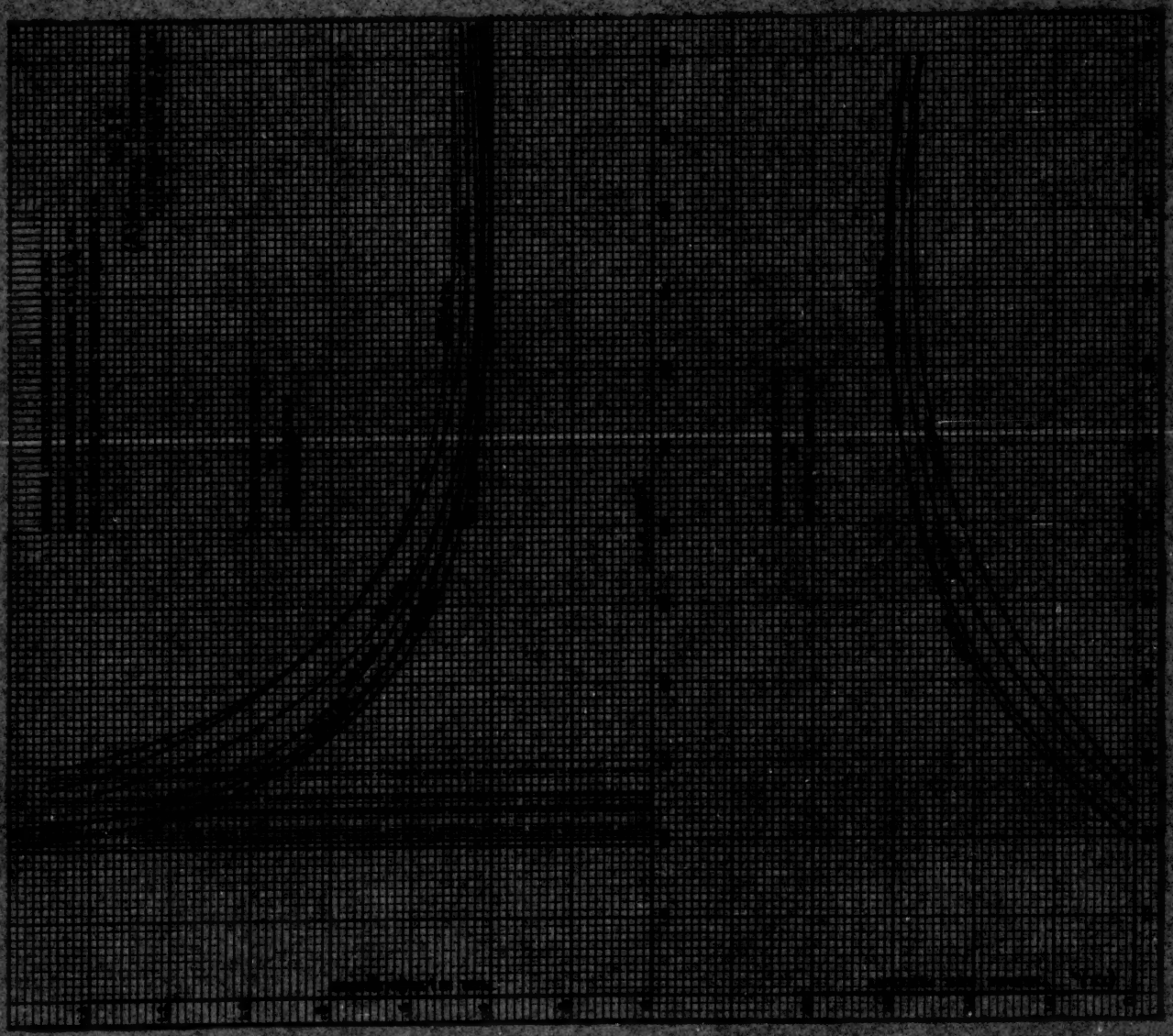








Sheet 9



COMPUTATIONS ON THIS SHEET ARE IN THE ORDER OF VARYING TORQUE CONSTANT R.P.M.

NOTE

ENGINE ALONE CONSIDERATION.

$$(B.H.P.)_{\text{OUTPUT}} = b.h.p._{\text{DUE TO TORQUE ON DYNA.}} + b.h.p._{\text{DRIVING THE AIR COMP.}} + b.h.p._{\text{DRIVING ATTACHED PUMPS}}$$

I No. OF TEST	II TORQUE IN LBS. ON DYNAMOMETER	III R.P.M.	IV AIR COMP. I.H.P.	V B.H.P. ABSORBED BY AIR COMP. IV/.9	VI B.H.P. ABSORBED BY PUMPS	VII B.H.P. DUE TO LOAD ON DYNAMOMETER	VIII $(B.H.P.)_{IN}$ TOTAL V+VI+VII	IX I.H.P. FROM INDICATOR CARDS	X MEAN EFF. FROM INDICATOR CARDS VIII/IX	XI Lbs. OF OIL PER B.H.P. HR.	XII FUEL Lbs/HOUR	XIII Lbs/I.H.P. HOUR XII/IX	XIV Lbs/B.H.P. HOUR XII/VIII	XV Lbs/I.H.P. FUEL	XVI T.M.P. THERMAL EFFICIENCY	XVII TIME EQUIV. OF STDG. B.H.P. HR.	XVIII TIME EQUIV. OF STDG. I.H.P. HR.
A_{12}	0	117	0	0	0	0	0	85	80	0	26.8	.315	~	.446	206.4	0	41.8
35	0	117	66.9	74.3	20	87	100	203.7	19.3	49	60.8	.2984	.608	1.013	468.9	21.9	48.6
1	¼	119	92.4	102.2	20	207.7	330.9	459.4	47.8	72.0	128.6	.2799	.3886	2.143	992.0	33.3	46.3
14	½	117	110.1	122.3	20	398.6	540.8	679.7	64.4	79.5	186.7	.2782	.3453	3.088	1432.7	37.7	47.4
31	¾	117	103.8	115.3	20	597.8	739.1	867.6	82.2	84.4	258.8	.2982	.3630	4.313	1996.5	36.7	43.4
39	Full	118	118.7	131.9	20	803.8	955.7	1067.6	109.2	89.5	335.7	.3144	.3517	5.595	2589.9	34.9	41.8
B_{12}	0	187	0	0	0	0	0	175	103	0	51.6	.295	~	.86	398.1	0	43.9
34	0	187	92.5	102.8	32	94	144.2	348.8	90.5	41.7	108.4	.2903	.6252	1.673	774.4	18.6	44.6
2	¼	190	147.1	163.4	32	323.6	519	749.0	69.7	69.2	207.7	.2773	.4001	2.462	1602.6	32.4	46.7
13	½	190	142.9	180	32	647.1	859.1	1117.8	68.2	76.8	302.5	.2706	.3521	3.041	2339.5	36.8	47.9
30	¾	190	153.6	170.7	32	970.7	1173.4	1448.3	84.5	81.0	408.6	.2800	.3486	4.76	3189.2	37.5	46.3
37	Full	189	186.6	207.3	32	1287.5	1526.3	1769.7	103.8	86.2	533.0	.3011	.3490	6.883	4119.0	37.1	43.0
C_{12}	0	215	0	0	0	0	0	225	116	0	64.1	.285	~	1.068	494.3	0	45.5
33	0	215	108.5	120.5	36	12.9	169.4	416.9	21.5	40.6	118.8	.2777	.6886	1.98	899.4	19.0	44.7
3	¼	217	168.0	186.7	36	349.6	572.3	859.3	49.9	68.9	237.2	.2760	.4004	3.955	1809.8	32.4	47.0
12	½	217	179.2	199.1	36	799.1	974.2	1323.3	62.6	73.6	347.6	.2626	.3568	5.793	2681.6	36.3	49.3
29	¾	217	171.8	190.5	36	1108.7	1335.2	1696.6	83.6	81.8	470.0	.2871	.3520	7.833	3625.9	36.8	45.1
36	Full	216	211.4	234.9	36	1471.4	1742.3	2081.7	103.6	86.3	613.0	.3036	.3518	10.216	4728.6	36.8	42.7
D_{12}	0	275	0	0	0	0	0	360	14.5	0	103.7	.288	~	1.728	799.9	0	45.0
32	0	275	125.0	138.9	46	16.5	201.4	590.4	88.1	34.1	189.8	.2707	.7924	3.163	1532.7	16.3	47.9
4	¼	277	184.1	182.3	46	471.7	700.	1156.9	66.3	60.6	307.8	.2660	.4397	5.13	2374.7	29.5	48.7
11	½	280	209.7	233.0	46	953.7	1232.7	1746.4	69.1	70.6	470.1	.2693	.3813	7.835	3626.0	34.0	48.1
18	¾	278	215.7	239.7	46	1394.8	1680.6	2116.5	88.9	79.4	607.2	.2870	.3613	10.12	4684.6	35.9	47.1
28	Full	276	238.8	265.5	46	1880.1	2213.4	2684.1	106.6	82.4	816.9	.3075	.3687	13.615	6277.0	35.1	46.1
E_{12}	0	312	0	0	0	0	0	430	15.2	0	129.0	.300	~	2.15	995.2	0	45.2
31	0	312	134.4	149.3	51	18.7	219	681.1	24.2	32.1	196.8	.2874	.8940	3.263	1510.4	14.5	47.1
5	¼	314	160.9	178.8	51	534.7	764.5	1170.9	48.4	55.7	358.2	.2612	.4685	5.97	2763.5	27.7	49.6
10	½	312	225.8	250.9	51	1062.7	1364.6	1885.5	67.1	72.2	522.9	.2768	.3831	8.718	4034.2	33.8	46.8
17	¾	310	238.9	265.4	51	1583.8	1960.3	2410.6	86.2	78.8	708.6	.2939	.3729	11.81	5466.9	34.7	44.1
24	Full	310	280.0	311.1	51	2111.7	2473.8	2977.6	106.9	83.2	947.7	.3188	.3880	15.795	7311.6	33.8	40.6
F_{12}	0	360	0	0	0	0	0	510	15.7	0	145.3	.286	~	2.421	1120.7	0	45.5
30	0	360	149.4	166.0	60	39.6	265.6	831.3	25.6	31.9	244.3	.2938	.9198	4.072	1884.9	14.1	44.1
6	¼	364	190.4	211.5	60	619.9	891.4	1384.5	51.3	52.9	449.4	.2667	.5041	7.49	3467.1	25.7	48.6
9	½	363	237.4	263.8	60	1236.4	1560.2	2295.6	70.1	67.9	645.3	.2811	.4136	10.755	4978.5	31.9	46.1
16	¾	364	265.4	294.9	60	1889.7	2249.9	3219.1	88.9	75.9	888.5	.2765	.4005	14.808	6854.7	32.9	45.6
23	Full	363	308.7	337.4	60	2472.8	2878.2	3877.6	109.1	80.3	1148.0	.3213	.3989	19.133	8854.8	32.4	40.5
G_{12}	0	391	0	0	0	0	0	690	19.5	0	207.0	.300	~	3.45	1597.0	0	45.8
29	0	391	147.2	163.6	70	56	289.6	1005.2	28.5	28.8	287.1	.2886	.9917	4.785	2215.0	13.1	45.4
7	¼	391	211.8	235.3	70	665.9	971.2	1745.9	49.5	55.6	504.4	.2889	.5193	8.406	3891.2	24.9	44.9
8	½	390	191.3	212.5	70	1328.3	1611.8	2386.3	67.8	67.5	738.5	.3096	.4581	12.308	5697.4	28.9	41.9
15	¾	393	298.2	331.4	70	2007.6	2410.2	3176.5	89.6	75.9	1014.0	.3192	.4207	16.9	7823.1	30.8	40.6
22	Full	393	320.9	356.5	70	2677.1	3103.6	3960.0	111.7	78.3	1316.0	.3323	.4240	21.933	10159.0	30.6	39.0

FULL TORQUE = 424,000 LBS. IN.

* TESTS A, B, C, D, E, F, G, HAVE NOT ACTUALLY BEEN PERFORMED, VALUES HAVE BEEN OBTAINED FROM CURVES

Sheet 13

COMPUTATIONS ON THIS SHEET ARE IN THE ORDER OF CONSTANT TORQUE VARYING R.P.M.

NOTE:

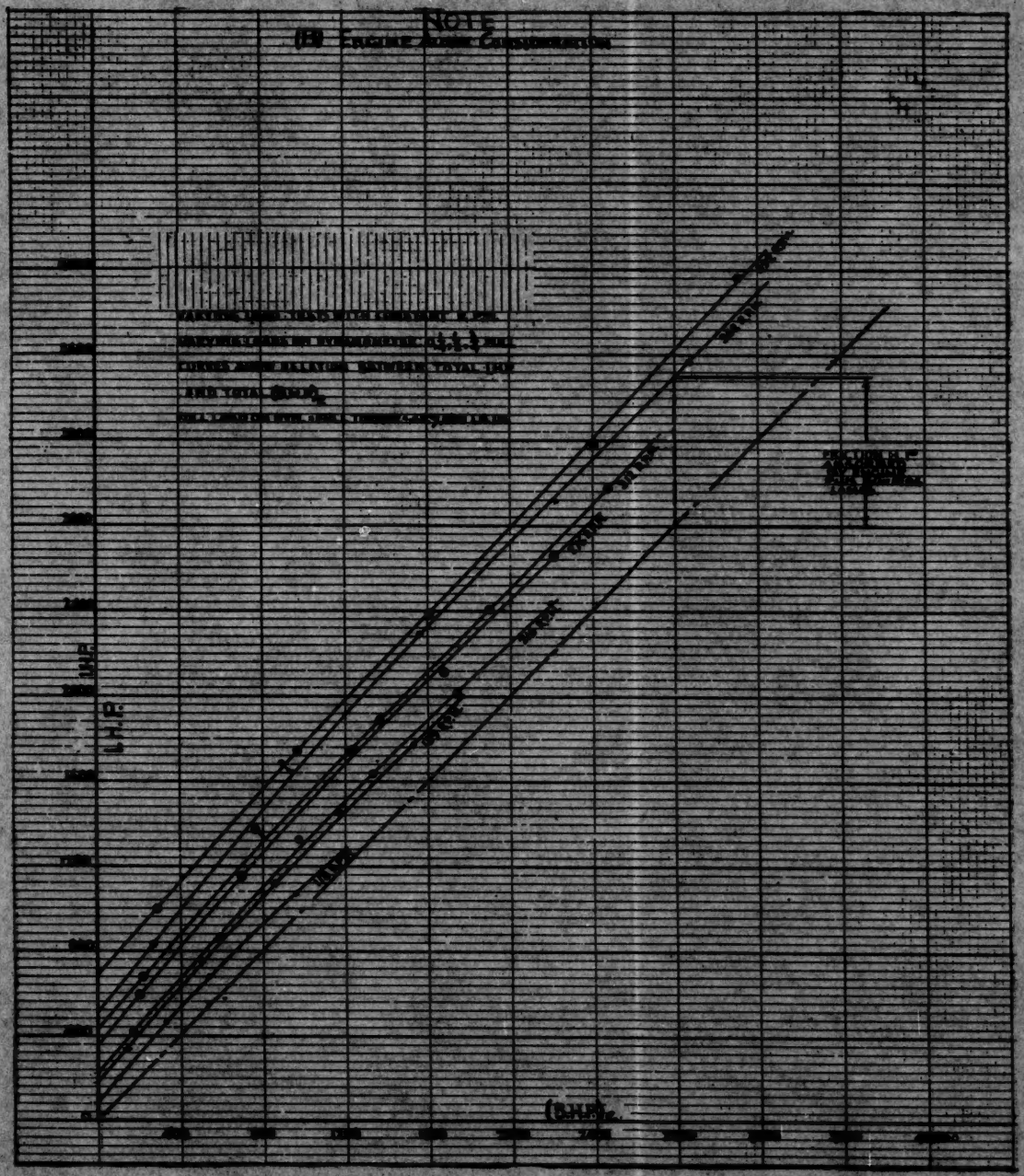
ENGINE ALONE CONSIDERATION.

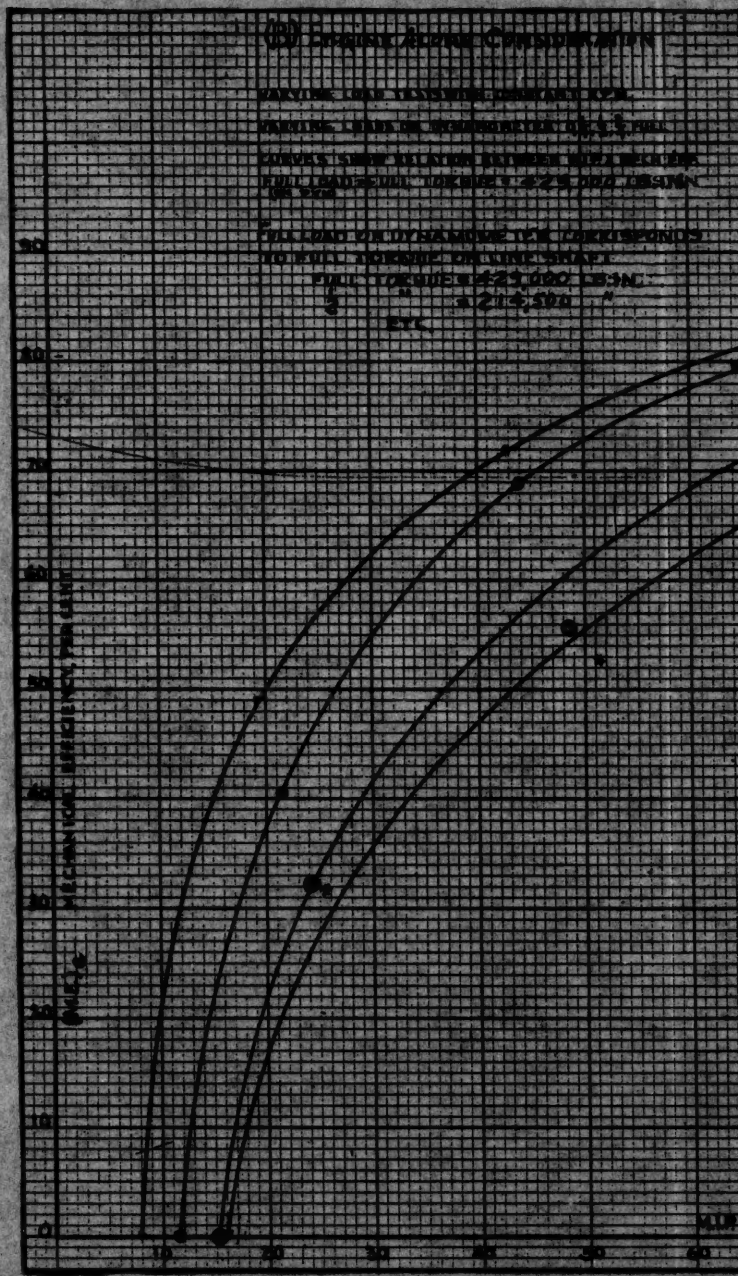
$$(B.H.P.)_{OUTPUT} = b.h.p._{\text{DUE TO WT. ON DYN.}} + b.h.p._{\text{DRIVING THE AIR COMP.}} + b.h.p._{\text{DRIVING ATTACHED PUMPS.}}$$

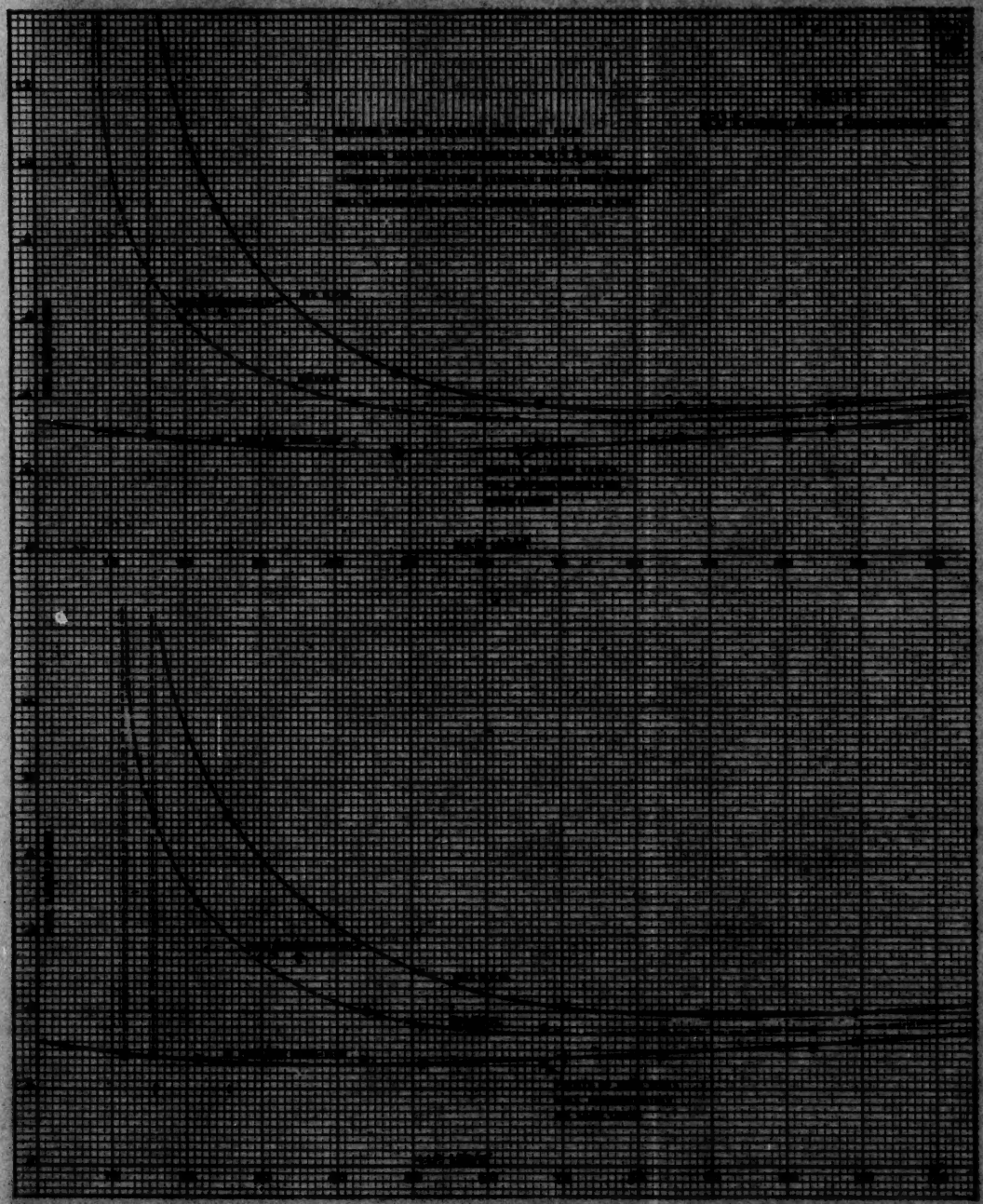
I NO. OF TEST	II TORQUE OR LOADS ON DYNAMOMETER	III R.P.M.	IV AIR COMP I.H.P.	V B.H.P. ABSORBED BY AIR COMP IV/.9	VI B.H.P. ABSORBED BY PUMPS	VII B.H.P. DUE TO LOAD ON DYNAMOMETER	VIII $(B.H.P.)_{E}$ TOTAL V+VI+VII	IX I.H.P. FROM INDICATOR CARDS	X M.E.P. FROM INDICATOR CARDS	XI MECH. EFF. OF ENGINE VIII / IX	XII LBS/B.H.P. FUEL	XIII LBS/I.H.P. HOUR XII / IX	XIV LBS/B.H.P. HOUR XII / VIII	XV LBS/MIN. FUEL	XVI T.H.P. THERMAL EQUIV. FUEL	XVII THER. EFF. OF ENG. B.H.P. 2545 / XVI	XVIII THER. EFF. OF ENG. I.H.P. 2545 / XV
A	0	117	0.	0.	0	0.	0.	87.	8.0	0.	26.8	.315	∞	.446	206.4	0.	41.2
B	0	187	0.	0.	0	0.	0.	175	10.3	0.	51.6	.275	∞	.86	398.1	0.	43.9
C	0	215	0.	0.	0	0.	0.	227	11.6	0.	64.1	.289	∞	1.068	494.3	0.	45.5
D	0	277	0.	0.	0	0.	0.	360	14.5	0.	103.7	.288	∞	1.728	799.9	0.	45.0
E	0	312	0.	0.	0	0.	0.	450	15.2	0.	129.0	.300	∞	2.15	995.2	0.	43.2
F	0	360	0.	0.	0	0.	0.	710	17.7	0.	145.3	.287	∞	2.421	1120.7	0.	45.5
G	0	391	0.	0.	0	0	0.	630	19.5	0	207.0	.300	∞	3.45	1597.0	0.	43.2
37	0	117	64.9	74.3	20	5.7	100.	203.7	19.3	49.	60.8	.2984	.608	1.013	468.9	21.3	43.4
34	0	187	98.5	102.8	32	9.4	144.2	345.8	20.5	41.7	100.4	.2903	.6968	1.673	774.4	18.6	44.6
33	0	215	108.5	120.5	36	12.9	169.4	416.9	21.5	40.6	115.8	.2777	.6835	1.93	893.4	17.0	44.7
32	0	275	125.0	138.9	44	16.5	201.4	530.4	23.8	38.1	139.8	.2707	.7334	2.663	1232.7	14.3	47.9
31	0	312	134.4	149.3	51	18.7	219.0	601.1	24.2	37.1	157.8	.2874	.8940	3.263	1510.4	14.5	47.1
30	0	360	148.6	166.0	60	23.6	265.6	831.3	25.6	31.9	214.3	.2938	.9198	4.072	1884.9	14.1	44.1
29	0	391	147.2	163.5	70	26.0	289.5	1005.2	28.9	28.8	207.1	.2856	.9917	4.769	2215.0	13.1	45.6
1	¼	119	57.4	108.2	20	282.7	330.9	479.4	48.8	72.0	128.6	.2799	.5886	2.143	992.0	25.9	46.3
2	¼	190	147.1	163.4	32	283.6	319.0	749.0	43.7	67.2	209.7	.2773	.4001	3.448	1602.6	22.4	46.7
3	¼	217	168.0	186.7	36	349.6	536.3	873.3	43.3	68.9	237.2	.2760	.4004	3.993	1089.8	22.4	47.0
4	¼	277	164.1	182.3	46	471.7	700.0	1134.9	46.9	60.3	307.8	.2660	.4397	5.13	2374.7	23.5	48.7
5	¼	314	160.9	178.8	51	534.7	764.5	1370.9	48.4	53.7	338.2	.2612	.4485	5.97	2763.5	22.7	49.6
6	¼	364	190.6	211.5	60	619.9	891.4	1604.5	51.9	52.9	449.4	.2667	.5041	7.49	3467.1	23.7	48.6
7	¼	391	211.8	235.3	70	665.9	971.2	1745.9	49.3	53.6	504.4	.2889	.5197	8.406	3891.2	24.9	46.9
14	½	117	110.1	122.3	20	536.5	700.0	672.7	64.4	73.5	185.7	.2732	.3433	3.095	1432.7	27.7	47.4
13	½	190	162.0	180.0	32	647.1	859.1	1117.5	65.2	76.8	302.5	.2706	.3521	5.041	2333.5	26.8	47.9
12	½	217	179.2	199.1	36	739.1	974.2	1329.3	67.6	73.4	347.6	.2626	.3568	5.793	2681.6	26.5	49.3
11	½	280	209.7	233.0	46	953.7	1232.7	1745.4	69.1	70.6	470.1	.2693	.5015	7.835	3626.8	24.0	48.1
10	½	312	235.8	250.9	51	1062.7	1364.4	1888.9	67.1	72.2	522.9	.2760	.3831	8.715	4034.2	23.8	46.0
9	½	363	237.4	263.8	60	1236.4	1560.2	2295.5	70.1	67.9	645.3	.2811	.4134	10.755	4978.5	21.3	46.1
8	½	390	191.5	212.5	70	1328.3	1611.8	2307.3	67.8	67.5	738.5	.3096	.4581	12.308	5697.4	20.3	41.9
21	¾	117	103.8	115.3	20	797.8	933.1	867.6	88.2	84.4	198.8	.2988	.3550	4.313	1996.2	36.7	43.4
20	¾	190	153.6	170.7	32	970.7	1173.4	1448.3	84.5	81.0	405.6	.2800	.3456	6.76	3129.2	37.5	44.9
19	¾	217	171.5	190.5	36	1108.7	1333.2	1636.5	83.6	81.5	470.0	.2871	.3520	7.833	3625.9	36.0	45.1
18	¾	273	215.7	239.7	46	1394.8	1680.5	2115.9	83.9	79.4	607.2	.2870	.3613	10.12	4684.6	35.9	45.1
17	¾	310	238.9	265.4	51	1583.0	1908.2	2410.6	86.2	78.8	700.6	.2939	.3789	11.81	5466.9	34.7	44.1
16	¾	364	266.6	296.2	60	1859.7	2217.9	2919.1	88.9	77.9	888.9	.3043	.4086	14.815	6854.7	32.3	42.6
15	¾	393	279.2	310.4	70	2007.8	2410.2	3176.9	89.6	75.8	1014.9	.3192	.4207	16.9	7823.1	30.8	40.6
28	FULL	118	118.7	131.9	20	803.8	955.7	1067.6	100.3	89.5	335.7	.3144	.3512	5.595	2589.9	36.9	41.2
27	"	189	186.6	207.3	32	1287.5	1526.8	1769.7	103.8	86.2	533.0	.3011	.3490	8.883	4112.0	37.1	43.0
26	"	216	211.4	234.9	36	1471.4	1742.3	2018.7	103.6	86.3	613.0	.3034	.3518	10.216	4729.0	36.8	42.7
25	"	276	258.8	287.5	46	1880.1	2231.6	2636.1	106.4	85.4	816.3	.3073	.3687	13.605	6297.8	33.1	42.1
24	"	310	280.0	311.1	51	2111.7	2497.8	2972.6	108.9	83.2	947.7	.3108	.3830	15.795	7311.6	33.8	40.6
23	"	369	309.7	337.4	60	2472.8	2870.2	3578.6	109.1	80.3	1148.8	.3213	.3999	19.133	8856.8	32.4	40.9
22	"	393	320.9	356.5	70	2677.1	3163.6	3980.8	111.7	78.3	1316.0	.3325	.4260	21.933	10153.0	30.6	39.0

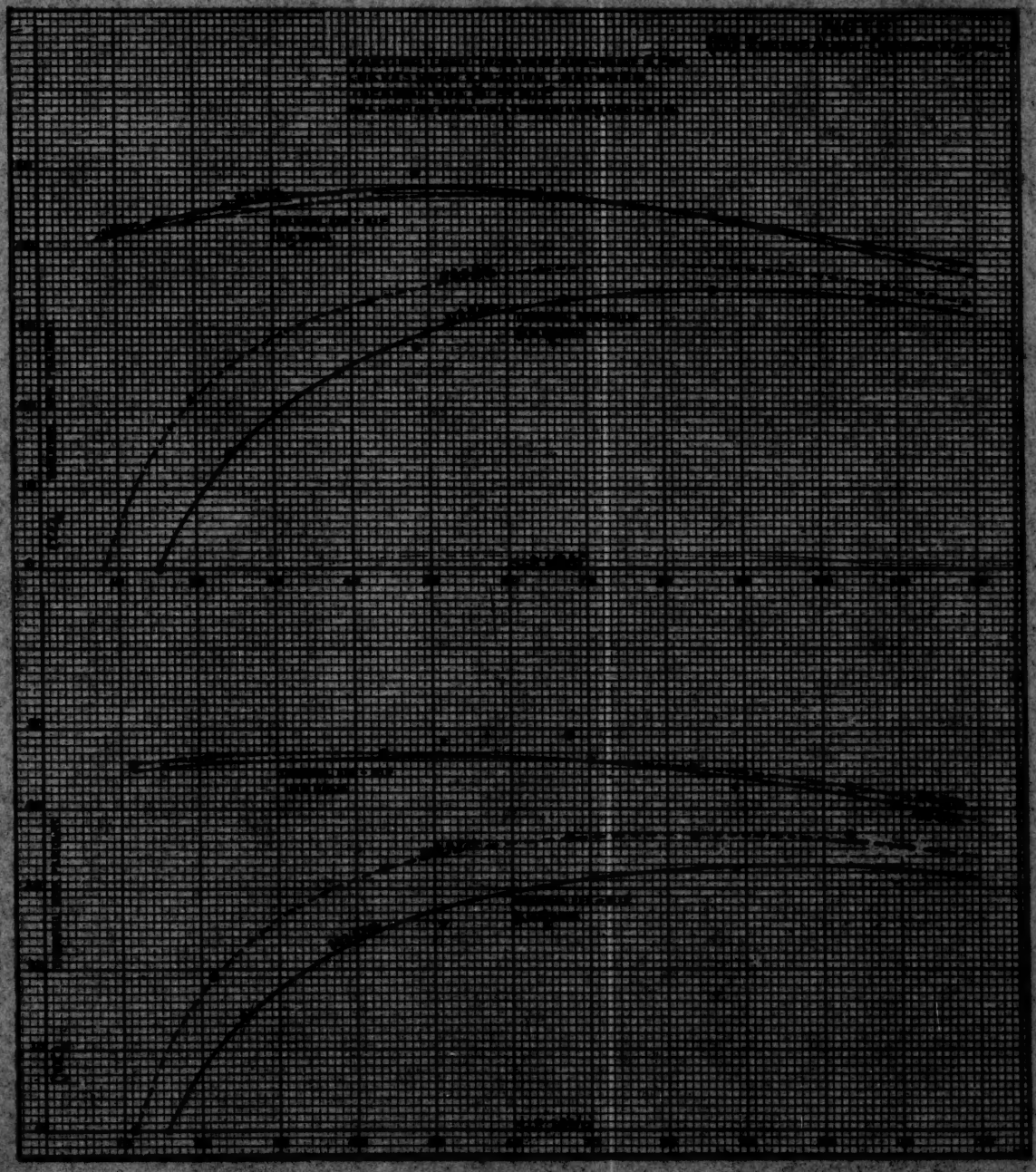
FULL TORQUE = 429,000 LB. IN

* TESTS A-B-C-D-E-F-G HAVE NOT ACTUALLY BEEN PERFORMED. VALUES HAVE BEEN OBTAINED FROM CURVES


NOTE
I.H.P.







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MECHANICAL MEANS FOR FINDING GEOGRAPHICAL POSITION IN NAVIGATION.

By G. W. Littlehales, Member.
HYDROGRAPHIC ENGINEER, UNITED STATES HYDROGRAPHIC OFFICE.

The form of mechanism to be described for solving spherical triangles, especially the astronomical triangle and the terrestrial triangles employed in navigation, does not partake of the nature of the globular type of mechanism in which, by means of arcs of graduated great-circles of the sphere representing the sides of the astronomical triangle, the solution is made after the manner of a graphical solution performed on the surface of a globe. The instrument herein outlined, being flat in form and adaptable to economy of space, may be placed on an instrument board.

THE THEORY OF THE FORM.

The fundamental relation between the arcs representing the three sides of a spherical triangle and the angle between two of them is generally expressed by trignometers in the following form

$$\cos a = \cos b \cos c + \sin b \sin c \cos A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which a, b, and c represent the sides and A the angle opposite the side a. This relation with reference to the other angles of the spherical triangle, *i.e.*, the angle B opposite to the side b, and the angle C opposite to the side c, can likewise be expressed by cyclical transposition of the letters in the usual manner; and similarly, from the polar triangle, comes the expression

$$\cos A = -\cos B \cos C + \sin B \sin C \cos a$$

If, in place of cos A, in equation (1), its equivalent $1 - 2 \sin^2 \frac{1}{2} A$ be introduced, the expression becomes

$$\cos a = \cos b \cos c + \sin b \sin c \,(1 - 2 \sin^2 \tfrac{1}{2} A) \quad . \quad . \quad . \quad (2)$$

or

$$\cos a = \cos b \cos c + \sin b \sin c - 2 \sin^2 \tfrac{1}{2} A \sin b \sin c \,. \quad (3)$$

or, since $\cos b \cos c + \sin b \sin c = \cos (b - c)$,

$$\cos a = \cos (b - c) - 2 \sin^2 \tfrac{1}{2} A \sin b \sin c \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and, since, $2 \sin^2 \tfrac{1}{2} A = \text{versin } A$,

$$\cos a = \cos (b - c) - \text{versin } A \sin b \sin c \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Subtracting both sides of the equation from unity,

$$1 - \cos a = 1 - \cos (b - c) + \text{versin } A \sin b \sin c \quad . \quad . \quad (6)$$

and, since $1 - \cos a = \text{versin } a$ and $1 - \cos (b - c) = \text{versin } (b - c)$,

$$\text{versin } a = \text{versin } (b - c) + \text{versin } A \sin b \sin c \quad . \quad . \quad . \quad (7)$$

but, $\sin b \sin c = \tfrac{1}{2} \left\{ \cos (b - c) - \cos (b + c) \right\} =$

$$\tfrac{1}{2} \left\{ \text{versin } (b + c) - \text{versin } (b - c) \right\}$$

hence

$$\text{versin } a = \text{versin } (b - c) + \tfrac{1}{2} \left\{ \text{versin } (b + c) - \text{versin } (b - c) \right\} \text{versin } A \quad . \quad . \quad (8)$$

Passing now to the usual notation of the astronomical triangle shown in Figure 1, which is the spherical triangle on the celestial

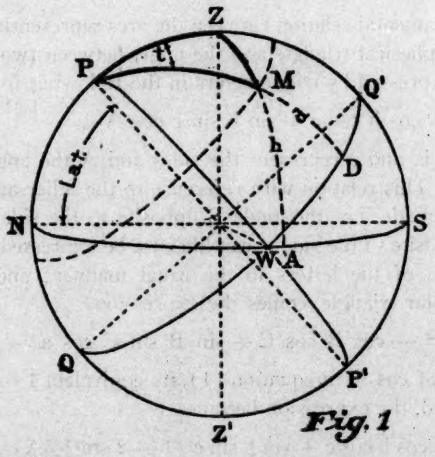


Fig. 1

concave whose three vertices are, respectively, the pole of the heavens, the zenith of the observer, and the observed celestial body, if the angle A be represented by t, the hour-angle, that is, the angle

at the pole included between the meridian of the observer and the hour-circle passing through the observed celestial body, then the side *a* will represent the zenith distance *z* of the observed celestial body, and the sides *b* and *c* may be taken to represent, respectively, the polar distance of the zenith and the polar distance of the observed celestial body, the first being equal to ninety degrees minus the latitude, 90 degrees — L, and the second to ninety degrees minus the declination, 90 degrees — d.

Equation (8), under this notation, takes the form

$$\text{versin } z = \text{versin } (L \sim d) + \left\{ \text{versin } [180^\circ - (L + d)] - \text{versin } (L \sim d) \right\} \frac{\text{versin } t}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

or, putting for 2 its equivalent, which is versin 180°, versin z =

$$\text{versin } (L \sim d) + \left\{ \frac{\text{versin}\{180^\circ - (L + d)\} - \text{versin } (L \sim d)}{\text{versin } 180^\circ} \right\} \text{versin } t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

For solving a time-sight to find the hour-angle and hence the longitude, equation (10) may be rewritten, thus

$$\text{versin } t = \frac{\{\text{versin } z - \text{versin } (L \sim d)\} \text{versin } 180^\circ}{\text{versin}\{180^\circ - (L + d)\} - \text{versin } (L \sim d)} \quad . \quad . \quad (11)$$

and, by analogy, for computing the azimuth, thus:

$$\text{versin } Z = \frac{\{\text{versin } (90^\circ \sim d) - \text{versin } (L - h)\} \text{versin } 180^\circ}{\text{versin}\{180^\circ - (L + h)\} - \text{versin } (L - h)} \quad (12)$$

in which Z represents the azimuth and h represents the altitude or complement of the zenith distance, that is, 90 degrees — z, as shown in Figure 1.

The forms of expression given in equations (10), (11), and (12) serve also to find the distance, the difference in longitude, and the course in Great Circle Sailing, by regarding *d* as the latitude of the place of destination, *t* as the difference in longitude between the points of departure and destination, *z* as the measure of the distance, and Z as the course from the position of the observer toward the place of destination.

Employing Cartesian rectangular coordinates, and letting

$$y = \text{versin } z$$
$$a = \text{versin } (L \sim d)$$
$$x = \text{versin } t$$
$$m = \frac{\text{versin } [180^\circ - (L + d)] - \text{versin } [L \sim d]}{\text{versin } 180^\circ}$$

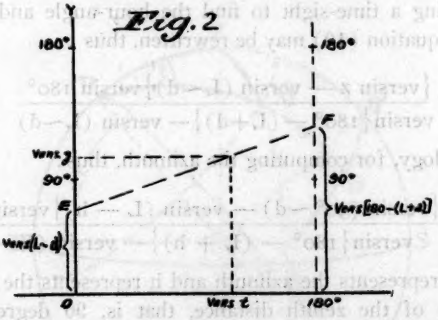
equation (10) will be transformed into

$$y = a + mx$$

which is the equation to a straight line intersecting the axis of Y at a distance *a* above the origin of coordinates and passing through the first quadrant at an angle of inclination to the axis of X whose tangent is *m*.

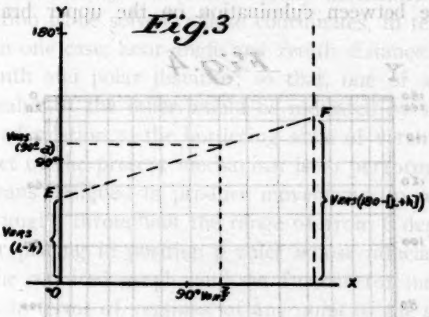
If the axes Y and X be graduated on the same scale to represent the versines of angles, commencing with 0 degrees at the origin designated by the letter O in Figure 2, and extending to 180 degrees in each case, the line EF will be the graph of the equation, $y = a + mx$, and hence of equation (10).

Fig. 2



The length of the ordinate to the line EF corresponding to any given value of *t* on the scale, OX, of abscissae representing the values of versin *t* will mark the value of *z* on the scale, OY, of ordinates representing the value of versin *z;* and, conversely, the abscissa corresponding to any given value of *z* (as when the altitude of a celestial body is measured in taking a time-sight) on the scale of ordinates, OY, will mark the value of the hour-angle *t* on the scale of abscissae, OX.

In like manner, equation (12) for finding the azimuth Z in which Z appears in place of t in equation (11) and the altitude, h, in place of the declination, d, may be represented by a straight line whose rectangular coordinates, as represented in Figure 3, are



versin Z and versin (90 — d) respectively, and whose inclination to the axis of abscissae in versin Z is an angle whose tangent is equal to

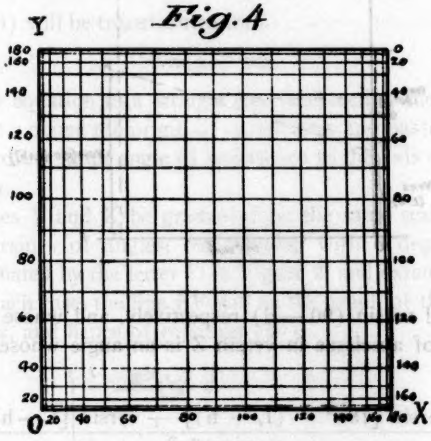
$$\frac{\text{versin } [180° - (L + h)] - \text{versin } [L \sim h]}{\text{versin } 180°}$$

The necessity for drawing coordinates after the manner shown by the lines of fine dashes in Figures 2 and 3 may, to a large extent, be obviated by extending the ordinates from the division marks of the scales of versines constructed along OX and OY, and thus forming a square diagram as shown in Figure 4.

If the righthand border of this diagram be numbered in the reverse order from the lefthand border, that is, from 180 degrees at the bottom to 0 degrees at the top, the righthand ordinate will be L + d in finding the hour-angle and zenith distance and L + h in finding the azimuth, instead of 180 degrees — (L + d) and 180 degrees — (L + h) as indicated in Figures 2 and 3 in these respective cases. Hence, the following rules provide for solving the equations (10), (11), and (12) to find, respectively, the zenith distance, the hour-angle or time-sight, and the azimuth, by means of the construction shown in Figure 4.

(*a*) To find the zenith distance, z, mark the value of $(L \sim d)$ on the lefthand border scale of versines and the value of $(L + d)$ on the righthand border scale of versines. The straight line drawn to connect these two markings is the graph of equation (10) representing the diurnal course of a celestial body whose declination in invariable between culmination on the upper branch of the

Fig. 4



meridian of the observer in latitude, L, and culmination on the lower branch of the same meridian. Mark the intersection on this graph of the vertical ordinate from the value of the hour-angle, t, found on the top or bottom border scale of versines. The horizontal line from this intersection will mark, on the lefthand scale, the value of the zenith distance, z.

(*b*) When the altitude, and hence the zenith distance, z, is known by measurement, by reversing the last two steps in (*a*), the hour-angle, t, may be found.

(*c*) To find the azimuth, Z, mark the value of $(L - h)$ on the lefthand border scale of versines, and the value of $(L + h)$ on the righthand border scale of versines. The straight line drawn to connect these two markings is the graph of equation (12). Mark the intersection on this graph with the horizontal line from the value of the polar distance, (90 degrees $-$ d), found on the left-

hand border scale of versines. The vertical ordinate from this intersection will mark, on either the top or bottom border scale, the value of the azimuth, Z.

In brief, these solutions consist in finding, in the form of a straight line connecting two points readily determined, the graph of the equation to be solved, whose coordinates, in terms of versines, are, in one case, hour-angle and zenith distance, and, in the other, azimuth and polar distance; so that, one of a pair being given, the value of the other would be indicated by the graph in its established relation to the bordering scale of versines.

The object of the present mechanism is to perform these solutions by means designed to produce movements, to represent the versines of angles throughout the range of from 0 degrees to 180 degrees, for placing in position a ruler whose fiducial edge shall represent the required graph, and yet further for measuring the coordinates, in terms of versines, of any point of the graph represented by the fiducial edge.

In a semicircle, if a radius be conceived to revolve from a position of coincidence with the diameter in one direction to a position in coincidence with the diameter in the opposite direction, the versine of the angle of removal of the radius from the initial position will be represented by the distance of removal from the extremity of the diameter at the origin of movement of the foot of the perpendicular let fall from the outer end of the revolving radius upon the diameter, as shown in Figure 5.

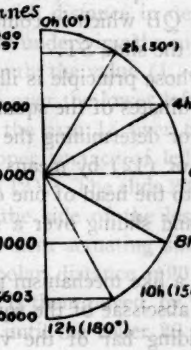


Fig. 5.

The motion of the foot of the perpendicular will be derived from that of the outer end of the revolving radius by the arrangement shown in Figure 6, in which P represents a small pin and block set in the outer end of a radius arm CP pivoted at the center of the

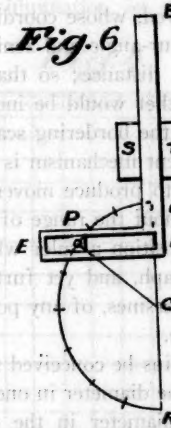


Fig. 6

graduated semicircular plate RPQ. Let the pin work in the slot EF whose direction is at right angles to the sliding bar QB which forms a part of the yoke EF. Of the components which combine to produce the circular motion of P, that which occurs in the direction EF is rendered inoperative, and the whole of the other is imparted to the bar QB which is confined to a rectilinear movement by the sides of the slide ST.

The mechanism whose principle is illustrated in Figure 6, being applied at the end-ordinates of the square forming the boundary of Figure 4, provides for determining the line of the graph of equation (10), or (11), or (12) by means of the fiducial edge of the bar or ruler pivoted to the head of one of the pair of members QB shown in Figure 6 and sliding over a support at the head of the other.

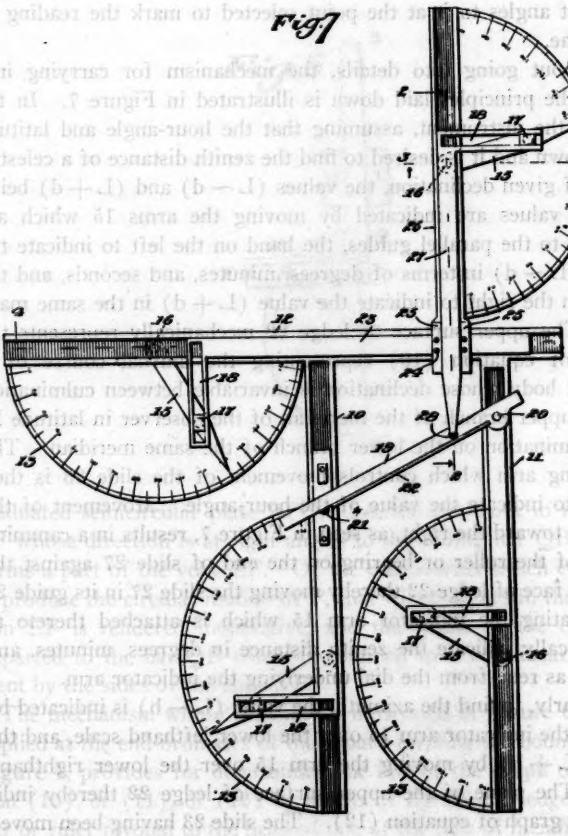
And, by means of a like mechanism placed in a position defined by the upper line of abscissae of the square forming the boundary of Figure 4, the sliding bar of the versine mechanism may be

moved to define the known abscissa of a point of the edge of the graph bar, whose other coordinate is then to be identified by the operation through contact with the graph bar, of the sliding mechanism carried by and fixed to the abscissa sliding bar, in a position at right angles to it at the point selected to mark the reading of abscissae.

Without going into details, the mechanism for carrying into effect the principles laid down is illustrated in Figure 7. In the use of the instrument, assuming that the hour-angle and latitude are known and it is desired to find the zenith distance of a celestial body of given declination, the values $(L \sim d)$ and $(L + d)$ being known values are indicated by moving the arms 15 which are pivoted to the parallel guides, the hand on the left to indicate the value $(L \sim d)$ in terms of degrees, minutes, and seconds, and the hand on the right to indicate the value $(L + d)$ in the same manner. The upper surface of ledge 22 mechanically represents the graph of equation (10) representing the diurnal course of a celestial body whose declination is invariable between culmination on the upper branch of the meridian of the observer in latitude L, and culmination on the lower branch of the same meridian. The indicating arm which controls movement of the slide 23 is then moved to indicate the value of the hour-angle. Movement of the slide 23 toward the right, as seen in Figure 7, results in a camming action of the roller or bearing on the end of slide 27 against the inclined face of ledge 22 thereby moving the slide 27 in its guide 26 and rotating the indicator arm 15 which is attached thereto to mechanically indicate the zenith distance in degrees, minutes, and seconds as read from the dial underlying the indicator arm.

Similarly, to find the azimuth, the value $(L - h)$ is indicated by moving the indicator arm 15 over the lower lefthand scale, and the value $(L + h)$ by moving the arm 15 over the lower righthand scale. The plane of the upper surface of ledge 22 thereby indicates the graph of equation (12). The slide 23 having been moved to its extreme position on the side of the lesser end-ordinate of the graph bar, the indicator arm actuating slide 27 is then set to indicate the value of the polar distance, (90 degrees $- d$), and, this being done, the slide 23 is then moved, by rotation of the indicator arm attached thereto, until the roller 28 of the slide 27 con-

Fig. 1



tacts with the ledge 22. At this point the indicator arm attached to the slide 23 will overlay the scale 13 at the point which directly indicates the value of the azimuth.

When the altitude, and hence the zenith distance, is known by measurement, the parallel slides being set for $(L \sim d)$ and $(L + d)$ as already described in finding the zenith distance, the hour-angle may be found by moving slide 23 to its extreme position on the side of the lesser end-ordinate of the graph bar, by next setting, to the value of the zenith distance, the indicator arm which is attached to the slide 27, and finally moving the slide 23 by rotation of the indicator arm attached thereto, until the roller 28 of slide 27 contacts with the ledge 22. At this point the indicator arm attached to slide 23 will overlay the scale 13 at a point which directly indicates the value of the hour-angle.

THE COFFIN HIGH SPEED BOILER FEED PUMP.

By Lt. Comdr. T. A. Solberg, U. S. Navy, Member.

The many advantages inherent in centrifugal or rotating machinery as compared with reciprocating types are resulting in the displacement of the latter in the field of auxiliary machinery just as they have already done in the field of prime movers. Rapid advances have been made in recent years in the design of turbine driven centrifugal boiler feed pumps and it is the purpose of this paper to describe one of this class of pumps and give some of the test results showing its performance.

In order to obtain the high pressure required for boiler feeding purposes the first centrifugal pumps were either multistage units or were made up of the necessary number of single stage pumps in series, the speeds in either system being relatively low. The present trend for this service seems to be toward the single stage high speed pump. This design takes advantage of the economy possible with a high speed turbine, has all the other advantages found in centrifugal pumps and does away with the complications of the multistage and multiple series units. Moreover, it has a much smaller weight and space factor which is specially desirable for marine and naval use.

The Coffin Feed Pump is a high speed centrifugal single stage boiler feed pump which was originally developed for use on locomotives. For such service, the following characteristics are desirable:

(1) Minimum space and weight. These factors are essential in order to enable the pump to be mounted on all types of locomotives. On the heavier types of engines very little increase of weight is allowable.

(2) Rugged construction. It must withstand the severe vibration and jolting continually encountered in this service.

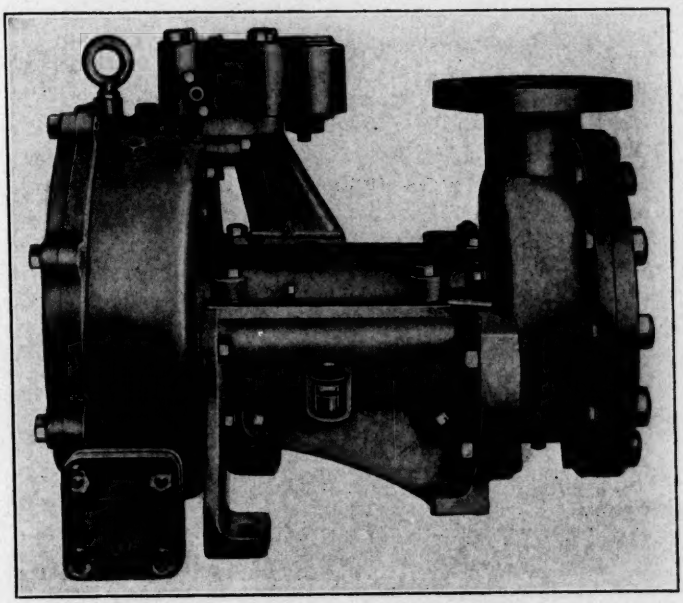


FIGURE I—THE COFFIN HIGH SPEED BOILER FEED PUMP.

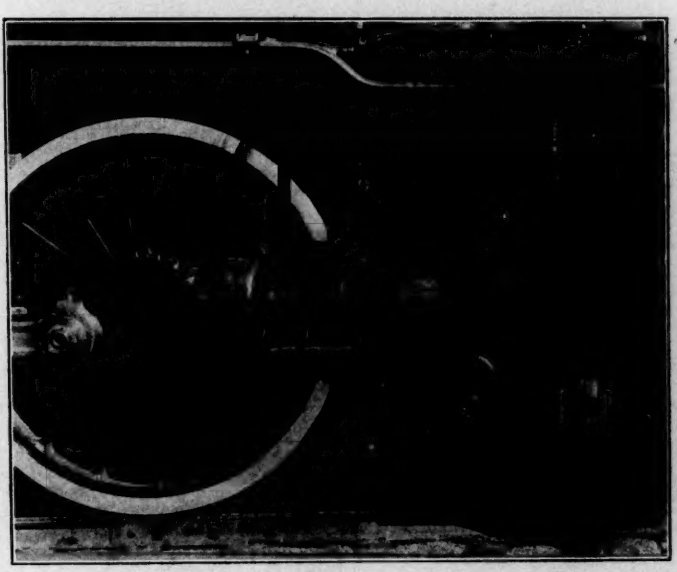


FIGURE VII.

(3) Reliability. Its location precludes oiling or making even minor repairs and adjustments while the engine is underway. Hence, it must be capable of running for long periods without attention.

(4) Overspeed protection. The pump should have some reliable controlling device to prevent overspeeding and consequent functioning of the overspeed or emergency trip, which would make the pump inoperative. This is accomplished by a combined throttle and control valve.

(5) Simplicity of application. It should be easily removable so that it can be replaced by a spare pump when extensive repairs become necessary.

(6) High operating efficiency and low maintenance costs.

(7) Simplicity. It must be capable of quick repair by usual mechanics employed.

The manner in which the above requirements are built into this pump, as well as the performance of the unit under test, will be described in the following pages. It would seem that the above qualifications would also make such a pump ideal for marine use.

GENERAL DESCRIPTION.

The pump is designed for 250 pounds per square inch delivery pressure at a capacity of 155 gallons per minute when operating on a steam pressure of 200 pounds per square inch at atmospheric exhaust pressure. The rated speed is 6800 R.P.M. Actually, the pump was run at 300 pounds delivery on 250 pounds steam pressure at a speed of about 7500 R.P.M., under which conditions the capacity was almost 200 gallons per minute. The present standard locomotive pump is equipped with slightly larger steam nozzles, and has a nominal rating of 200 G.P.M. against 250 pounds head with 200 pounds steam pressure.

Figure I is a photograph of the pump which shows the small space occupied. It can be seen that the unit is supported on a central casting, the turbine casing being secured to one side and the pump to the opposite. This casting carries the two pump bearings and is also the means of securing the pump in place. Both the turbine and pump casing have end covers and otherwise are solid in distinction from the usual split type of case.

The turbine is of the impulse type, having a single wheel with two velocity stages with removable reversing buckets between stages. There are two steam nozzles in the upper part of the casing. The turbine casing is of grey cast iron, closed at the end by a cast iron cover. The wheel is keyed to the shaft on a taper fit and secured on the shaft with a nut. The blading is of a special copper aluminum corrosion resisting alloy, the shrouding being integral with the blades. Leakage along the shaft end is prevented by two sets of labyrinths with a half-inch drain to the atmosphere between the two.

The pump casing is of bronze, with a removable diffuser ring. The pump suction is at the center and the delivery at the top of the casing. The impeller is also of bronze and has an extended hub, which serves to completely cover the pump shaft within the casing and thus prevents water from coming in contact with any steel. The impeller is screwed and pinned to the shaft. The entrance to the wheel consists of a nozzle screwed on the impeller. Leakage from the discharge side to the suction side is prevented by a labyrinth and a set of soft packing. A drain between these two, which is piped back to the suction side, removes the bulk of the leakage and, hence, makes the service required of the packing much less severe. The areas of the wheel exposed to the delivery and suction pressures are so proportioned as to just balance these pressures and, hence, there is practically no axial thrust in either direction.

The shaft is of chrome nickel steel and is carried by two precision type single row ball bearings mounted in the center casting. These bearings each have a thrust plate opposite the outer ball race. Between the thrust plate and ball race of one bearing are four small springs which serve to allow the shaft an axial float of about 1/32-inch. Between the two bearings the shaft is covered by the overspeed trip mechanism and two double cone oil bushings. Oil rings carry oil from the oil reservoir in the bottom half of the center casting to the oil cones, from which it is thrown into the bearings. The top half of the outer casting, which is removable, makes this a dirt and moisture proof enclosure for the bearings and oil reservoir. The reservoir holds about two pints of oil and, since no other parts require oiling, the unit will operate for several weeks with no attention in this respect.

The emergency overspeed trip device is of an unusual type, a sleeve with a flange at one end, which surrounds the shaft and is located between the two oil cones mentioned above, serves as a support for the elements which respond to the centrifugal force. The two weights are formed by splitting longitudinally a cup with a hole in its bottom, thus forming half cylinders with inside flanges. The fulcrum at the outside edge of their flanged ends on the flange of the supporting sleeve. When their open ends fly out under the influence of excessive speed the ends of their inside flanges impart an axial motion to the follower sleeve which has an inside flange sliding on the supporting sleeve. This motion is resisted by a coil spring inside of the follower and surrounding the supporting sleeve which bears at one end on the inside surface of the follower flange, and at its other end bears on the adjusting nut which is threaded in the supporting sleeve. The open end of the follower sleeve which surrounds and is centered by this nut is formed into an axial cam surface. This surface trips a latch when the follower sleeve is moved in an axial direction against it by the flying out of the weights and this allows the spring actuated trip mechanism to function and close a butterfly valve ahead of the steam nozzles. Figure II gives one view of the entire trip mechanism.

CONTROL VALVE.

Since the pump is inaccessible when the engine is underway, some method of preventing overspeeding and consequent tripping out must be provided. Instead of the constant speed governor frequently used for this purpose, a special type of control valve is used. Figure VI shows a cross section of this valve. It is seen to consist of a balanced steam valve and plunger. The main valve has an auxiliary valve which, as soon as the handwheel is turned to any open position, allows sufficient steam to flow to make the unit run at its idling speed. The base of the plunger is acted upon by the delivery water pressure so that as soon as the pump builds up a pressure above the steam pressure to the pump at the nozzles, the main valve is forced open to the limit previously set by the handwheel. Any condition — such as loss of pump suction, air or vapor binding, or overloading of the pump — which would cause

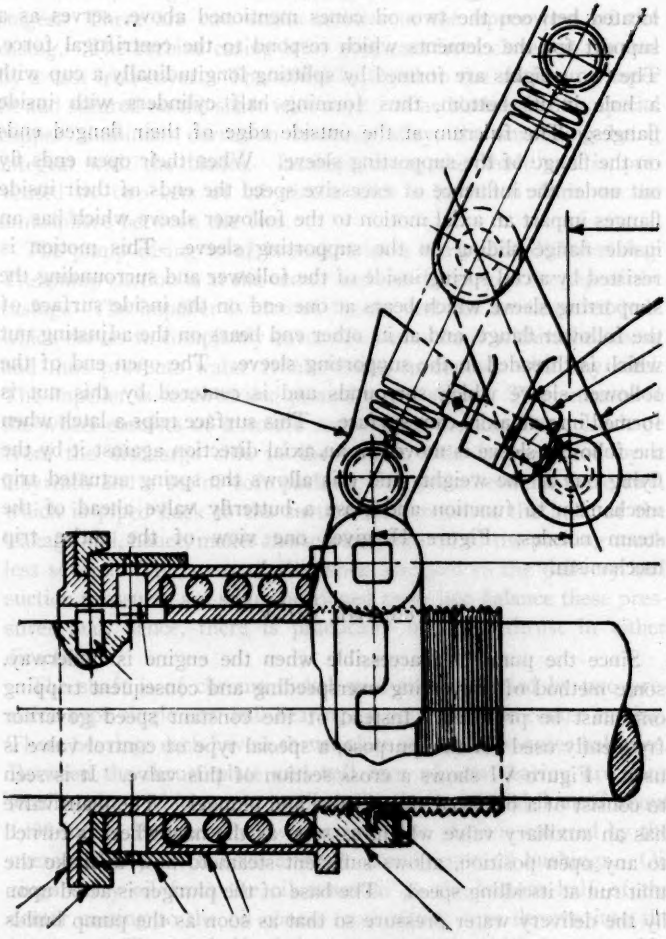
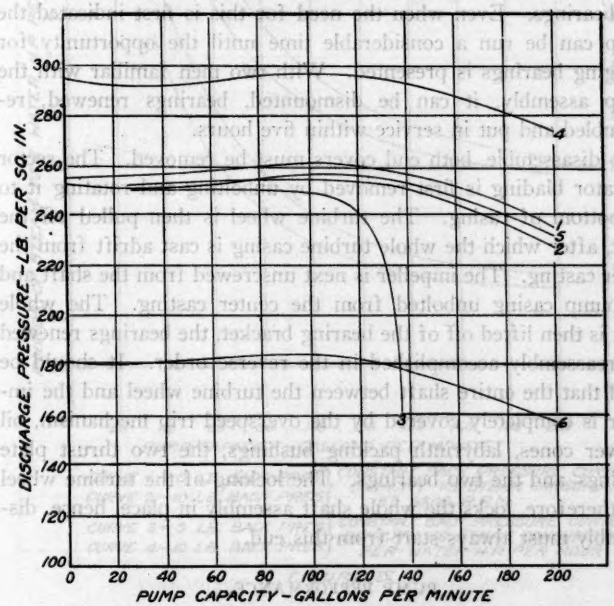


FIGURE II—EMERGENCY SPEED TRIP.

the delivery pressure to drop below the nozzle steam pressure, and consequently result in overspeeding, results in the unbalanced pressure closing the main valve and, as a result, the pump returns to its idling speed. Whenever the disturbing or abnormal conditions are removed and the discharge pressure again builds up, the main valve will open up to the limit previously set by the handwheel. This valve therefore serves as a throttle valve, as well as a control valve and obviates the use of a mechanical constant speed governor. It should be noted that the overspeed trip is normally set to function at 8800 R.P.M. Considering the characteristics of the pump, it is evident that a steam pressure in excess of 300 pounds gauge would be necessary to produce this speed under normal conditions. This is apparent from curve 4 of Figure III.



CURVE 1 – 5 FT. SUCTION HEAD
CURVE 2 – 9 FT. SUCTION LIFT
CURVE 3 – 16 FT. SUCTION LIFT
} CAPACITY VS. DISCHARGE HEAD CURVES - 6800 R.P.M.

CURVE 4 – 7300 R.P.M.
CURVE 5 – 6800 R.P.M.
CURVE 6 – 5800 R.P.M.
} CAPACITY VS. DISCHARGE CONSTANT SPEED CURVES

FIGURE III

In a test of the functioning of control valve the pump was allowed to run at its idling speed with the suction open to the atmosphere. After a half-hour's run under these conditions, the pump showed no ill effects; there was a rise in temperature of the whole pump casing to about 150 degrees Fahrenheit, but no damage from rubbing under the dry conditions was noticeable. The weight of the control valve is 23 pounds.

PUMP ASSEMBLY.

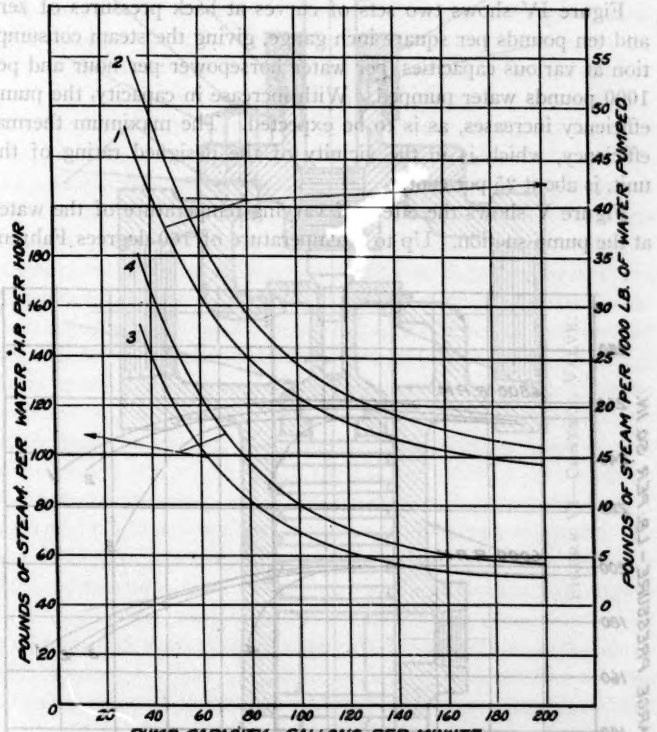
The assembly features of this unit are very well worked out. To begin with, the total weight is only 381 pounds, so that removal and replacement with a spare is easily accomplished, if necessary.

The only repair likely to become necessary is renewal of the two ball bearings. Even when the need for this is first indicated the pump can be run a considerable time until the opportunity for changing bearings is presented. With two men familiar with the pump assembly, it can be dismounted, bearings renewed, reassembled and put in service within five hours.

To disassemble, both end covers must be removed. The sector of stator blading is first removed by unbolting and rotating it to the bottom of casing. The turbine wheel is then pulled off the shaft, after which the whole turbine casing is cast adrift from the center casting. The impeller is next unscrewed from the shaft and the pump casing unbolted from the center casting. The whole shaft is then lifted off of the bearing bracket, the bearings renewed and reassembly accomplished in the reverse order. It should be noted that the entire shaft between the turbine wheel and the impeller is completely covered by the overspeed trip mechanism, oil thrower cones, labyrinth packing bushings, the two thrust plate bushings, and the two bearings. The locking of the turbine wheel nut, therefore, locks the whole shaft assembly in place, hence, disassembly must always start from this end.

PUMP PERFORMANCE.

The curves of pump performance are shown on Figures III, IV, and V. On Figure III are shown capacity versus discharge curves for various suction heads at 6800 R.P.M., and various constant speed curves. All of these curves show that the pump has un-



CURVE 1 – 0 LB. BACK PRES. } CONSTANT BACK PRESSURE CURVES CAPACITY VS. STEAM CONSUMPTION AT 6800 R.P.M.
CURVE 2 – 10 LB. BACK PRES. }

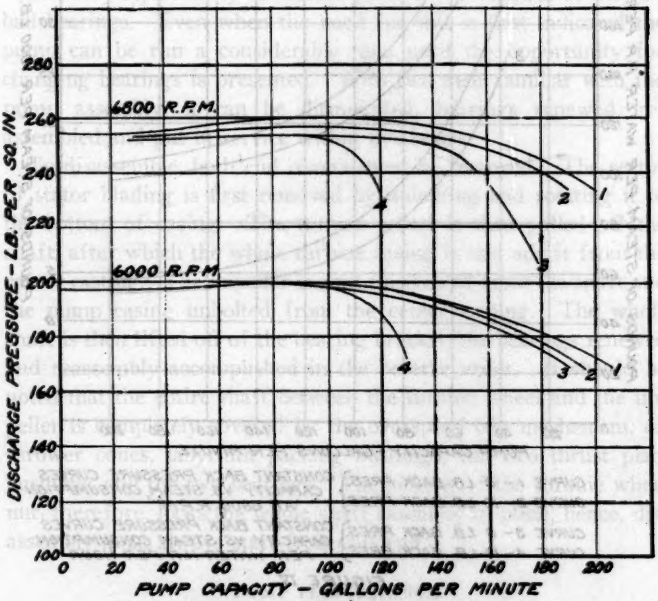
CURVE 3 – 0 LB. BACK PRES. } CONSTANT BACK PRESSURE CURVES CAPACITY VS. STEAM CONSUMPTION PER WATER H.P. PER HOUR
CURVE 4 – 10 LB. BACK PRES. }

FIGURE IV

usually flat characteristics. With increasing suction lifts there is a gradually increasing drop in total head which becomes pronounced at lifts greater than nine feet.

Figure IV shows two sets of curves at back pressures of zero and ten pounds per square inch gauge, giving the steam consumption at various capacities, per water horsepower per hour and per 1000 pounds water pumped. With increase in capacity, the pump efficiency increases, as is to be expected. The maximum thermal efficiency, which is in the vicinity of the designed rating of the unit, is about 25 per cent.

Figure V shows the effect of varying temperature of the water at the pump suction. Up to a temperature of 160 degrees Fahren-



PUMP CAPACITY VS. DISCHARGE PRESSURE CURVES
CURVES 1 - COLD WATER
CURVES 2 - 160° FAHR.
CURVES 3 - 180° FAHR.
CURVES 4 - 200° FAHR.

FIGURE V

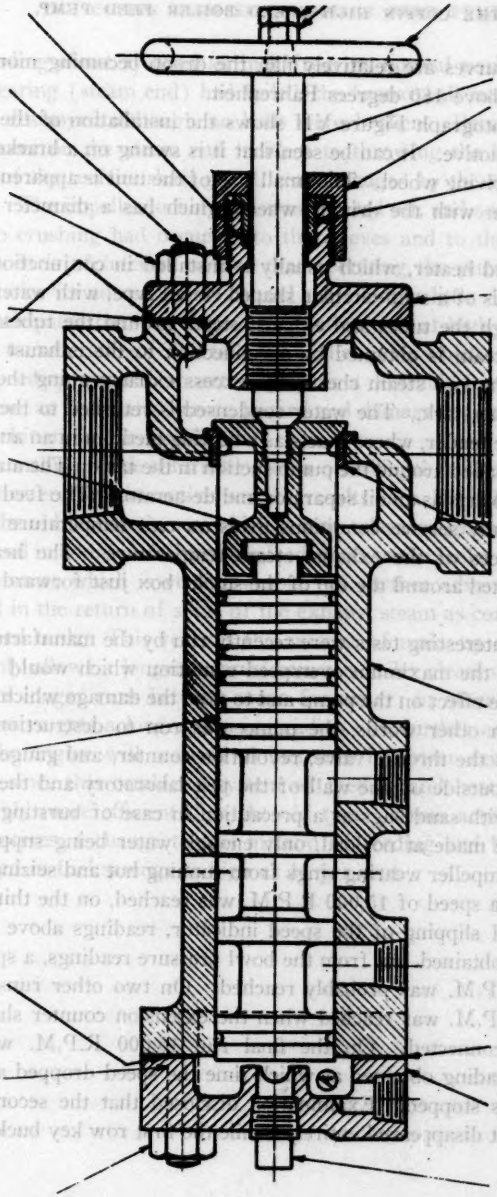


FIGURE VI—CONTROL VALVE.

heit, the curves are relatively flat, the droop becoming more pronounced above 180 degrees Fahrenheit.

The photograph Figure VII shows the installation of the pump on a locomotive. It can be seen that it is swung on a bracket near the rear driving wheel. The small size of the unit is apparent from comparison with the driving wheel, which has a diameter of 79 inches.

The feed heater, which usually is installed in conjunction with the pump is of a semi-circular shaped closed type, with water passing through the tubes and exhaust steam around the tubes. The exhaust steam is obtained by a connection to the exhaust saddle between the two steam chests, the excess exhaust going the usual route to the stack. The water condensed is returned to the water tank in the tender, where it acts as a heating medium in an auxiliary heater installed around the pump suction in the tank. The auxiliary heater also acts as an oil separator and de-aerator. The feed heater under steady service conditions gives an exit temperature within nine degrees of the exhaust steam temperature. The heater is usually fitted around the top of the smoke box just forward of the stack.

Some interesting tests were recently run by the manufacturer to determine the maximum overspeed condition which would have a destructive effect on the pump and to note the damage which would occur. In other words, the pump was run to destruction. On these tests the throttle valve, revolution counter, and gauges were mounted outside on the wall of the test laboratory and the pump covered with sand bags as a precaution in case of bursting. The runs were made at no load, only enough water being supplied to keep the impeller wearing rings from running hot and seizing. On two runs a speed of 15,000 R.P.M. was reached, on the third run, because of slipping of the speed indicator, readings above 10,000 were not obtained, but from the bowl pressure readings, a speed of 18,000 R.P.M. was probably reached. On two other runs about 12,000 R.P.M. was reached when the extension counter shaft became disconnected. On the final run 15,000 R.P.M. was the highest reading obtained at which time the speed dropped and the pump was stopped. Examination disclosed that the second row key bucket disappeared entirely, while the first row key bucket was

protruding about 1/32 of an inch from its normal position. The ball bearing (steam end) had failed, the bronze ball retaining ring being destroyed although no balls were broken. Because of the unbalance on the steam end incident to throwing the key bucket, parts of the turbine shaft gland were damaged by the whip of the shaft. The impeller locking pin was sheared off, and some damage due to crushing had occurred to the sleeves and to the governor body. It is of interest to note that operating the pump at much over twice its normal speed caused surprisingly little damage and the anticipated bursting commonly encountered at high overspeeds failed to materialize. The failure of other parts which will prevent overspeeding up to the bursting point is a desirable feature in any machine, as it obviates human hazard and damage to other material or machinery in the vicinity.

In conclusion, the substitution of a centrifugal feed pump and a feed heater for locomotive service results in a large fuel saving over the old injector type (which is now relegated to standby service), and in addition delivers the feed water to the boiler at a higher temperature which is very desirable. A further advantage is obtained in the return of some of the exhaust steam as condensate to the feed tank. This reduces the amount of make-up feed which not only allows a longer interval between boiler cleanings but also enables longer runs between stops for water; in other words the locomotive gets a longer cruising radius. A further advantage is that the engine will respond to increases in power demand more easily since this combined system of feeding and heating is considerably more efficient than the old type. From actual tests on locomotives, a change to this method of feeding and heating has resulted in fuel savings as high as 14 per cent.

AIRSHIP PROGRESS AND AIRSHIP PROBLEMS.

By Commander Garland Fulton, (CC) U. S. N., Member.

The Navy Department has awarded a contract for the construction of two rigid airships, greatly surpassing in size and performance any other airships built or building in the world. The magnitude of the advance in the art of airship design may be judged by the comparison presented in the following table between the principal characteristics of the new airships, *ZRS-4* and *ZRS-5*, designed in 1928, and the Navy's only rigid airship in service at present, the U. S. S. *Los Angeles*, designed in 1922 and completed in 1924:

PRINCIPAL CHARACTERISTICS OF THE "LOS ANGELES" AND THE "ZRS-4."

(Inflated with Helium.)

	Los Angeles	*ZRS-4*
Nominal Gas Volume, cubic feet	2,470,000	6,500,000
Length overall, feet	658.3	785
Maximum diameter, feet	90.7	132.9
Height overall, feet	104.4	146.5
Gross lift, pounds	153,000	403,000
Useful lift, pounds	60,000	182,000
Number of engines	5	8
Total horsepower	2000	4480
Maximum speed, knots	63.5	72.8
Range without refueling, at 50 knots cruising speed, nautical miles	3500	9180

It is particularly striking that the new airships can go more than two and a half times as far as the *Los Angeles* without refuelling. Since the function of these naval airships will be long distance scouting at sea, the great range of the new ships is of the utmost value.

Probably the most outstanding novelty will be the provision of a complete airplane hangar within the hull of the airship, capable of housing five high performance airplanes. The airplanes may be raised or lowered on a trapeze swinging through large sliding

doors in the bottom of the hangar. Airplanes intended for use with the airship will be equipped with special hooks above their wings for attaching to the trapeze.

Externally, the new airships will appear fuller and less slender than the *Los Angeles*. The fair lines of the hull will not be disfigured as in past practice by external cars containing the engines. The engines will be housed within the hull, thereby reducing the resistance. The propellers will be supported on brackets from the hull, driven by the engines through transverse shafts and bevel gears. An important and interesting feature is that the propeller axes can be turned into the vertical position to exert a certain amount of up or down thrust to assist in taking off or landing the airship.

The hulls of the new airships, like their predecessors, will consist of duralumin longitudinal and transverse girders, with steel wire bracing. The girders will be of a new type, stronger and more efficient than hitherto used. The outside will be covered with the characteristic aluminized fabric, drawn smooth and tight. The buoyant helium will be contained in eleven separate cells of gas-tight fabric. The strength of the hull will be sufficient for storm or squall conditions approximately twice as severe as the *Los Angeles* could successfully encounter.

A notable improvement will be the provision of no less than three longitudinal corridors, and passageways completely around the circumference of each main transverse frame, giving access to all parts of the ship, so that inspection and repairs can be carried out in flight with a facility never before possible. The most modern radio equipment will be carried.

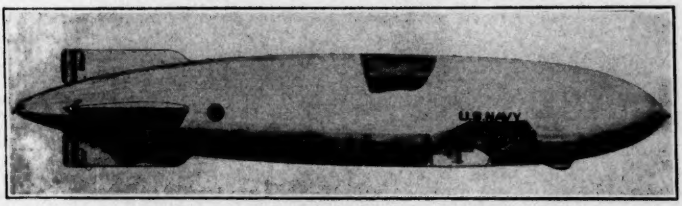
Airship duty is arduous and nothing is more important in a cruising airship than provision of adequate quarters for the officers and men, including comfortable sleeping and messing rooms, well warmed and ventilated, and ample cooking facilities to make sure that there will be no lack of warm food and drink to men undergoing the strain of days and nights of continuous flying. In the design of the new airships, particular attention has been given to the comfort of the crew. Being naval vessels, they will have no luxurious passenger accommodations; but in habitability for their crews, they will compare favorably with destroyers.

CONSTRUCTION.

As a result of the Navy Department's experience with rigid airships, starting nearly ten years ago the present "state of the art" in the United States may be summarized as follows: One rigid airship (the *Shenandoah)* has been built and operated successfully. Another, the *Los Angeles,* has been acquired and is still being operated successfully. Much thought and experimental effort has been applied to the engineering problems connected with airships. Technical personnel familiar with airships are available, both those self-trained in the United States and those who have been brought to this country. The technical knowledge and experience available in the United States to be applied to the design and construction of rigid airships is at least equal to that of any other country. Materials of all kinds are available that are the equals if not superior to those available elsewhere. Notable examples are aluminum alloys, cotton fabrics, gas cell materials of various kinds, wire, engines and power plant equipment including water recovery apparatus. Helium, available only in the United States, gives to airships a measure of safety that can not be denied. Promising solid injection oil engine development is underway here.

From a technical standpoint, the United States is prepared to design and build rigid airships to any required degree of engineering exactitude with assurance that the airships will accurately fulfill the requirements laid down. American ingenuity is ready to apply production methods to airship construction and thereby reduce their costs to offset the present high cost differential between American and foreign built airships.

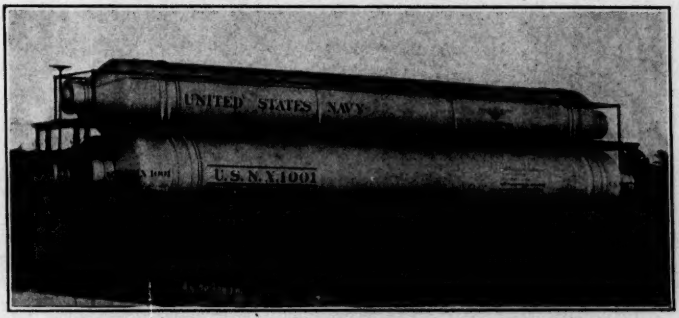
While structurally an airship can be designed and built to meet precisely a given set of conditions, there is still lack of agreement as to what conditions represent the worst that may be encountered by an airship. Before a satisfactory answer to this question can be had we must know more about the structure of gusty air. Turbulent air, rather than any maneuver the airship can be subjected to in smooth air through use of engines and rudders, represents the most severe condition an airship can encounter. Naturally, the handling of an airship under turbulent air conditions tests the knowledge and skill of the airship pilot.



(*Navy Photo.*)

FIGURE 1.

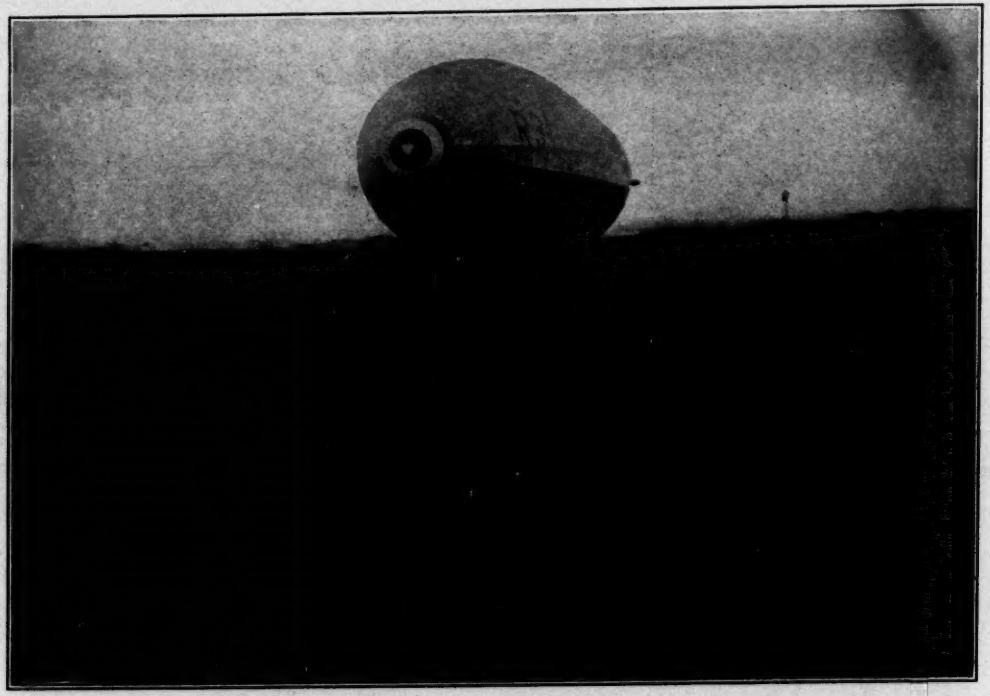
Sketch illustrating the important features of the two 6,500,000 cubic feet volume rigid airships recently contracted for by the Navy Department.



(*Navy Photo.*)

FIGURE 2.

Existing type of tank car for transporting and storing helium. Capacity 200,000 cubic feet of helium at 2,000-pound pressure.



(Navy Photo.)

FIGURE 3.

Servicing the British Airship R-34 at Mitchell Field, Long Island, following her trans-oceanic flight in July, 1919. Army troops held the airship on the open field for twenty-four hours during fuelling and gassing. Hydrogen was supplied through fabric tubing from the small cylinders shown in the foreground. The airship used the "three point method" or tripod arrangement of cables for mooring. One of her officers, General Maitland, descended by parachute and supervised the landing operation.

The weather conditions which interest the airship designer and the airship navigator most are storm winds, squalls, and sudden gusts, especially those not accompanied by clouds and precipitation. Given definite information of the intensity, extent, etc., of these conditions, the designer and navigator can take steps necessary to surmount their effects. Since detailed information of these conditions was not, prior to the development of aeronautics, of wide interest or importance, our present knowledge is far from complete.

Following the loss of the *Shenandoah*, increased attention has been devoted to the structure of gusts and the determination of worst atmospheric conditions. A program is under way both here and abroad that should yield valuable information. In time, as data is accumulated, it may prove practicable to define a condition or conditions, analogous to the Naval Architect's "theoretical wave" that will enable airships to be designed and built more along the empirical lines that have grown up and stand as proved over a period of years in vessel construction. For the present, however, the airship designer must carry through his stress analysis in painstaking detail and for his most severe conditions must rely on judgment and such lessons as the past have taught, trying to err always on the side of safety. 1928 airships will be substantially twice as strong as 1922 airships. While it is perfectly feasible to increase the longitudinal strength of an airship by adding only a moderate increase in weight, there is a limit to which this increase can in reason be allowed.

There will always remain certain storm disturbances that will wreck any airship, airplane, house or bridge that encounters the fury of the elements. We can not alter the weather; we must predict it and avoid dangerous conditions. For this reason improved weather service, including especially the now scantily covered ocean areas, is a necessity for the development of long aerial routes. Plans to this end are now underway and this service will come as soon as there is a demand for it, just as good roads followed in the wake of automobiles.

Some progress has been made toward development of means of locating and forecasting severe atmospheric disturbances. Further progress depends upon much more intensive and persistent

research. A thunderstorm indicator utilizing electro-static principles was purchased and prepared for installation on the *Los Angeles* a year ago. A promising line of development lies in the use of electro-magnetic disturbances as an indication of violent wind conditions. Instruments for this purpose are under test and others are being purchased for test.

OPERATION.

Besides adequate weather information service, the successful operation of rigid airships must depend on trained personnel; the availability of suitable facilities; and on experience.

The American personnel which has been trained in rigid airship operation is the equal of any. They have been very largely self-taught but the foundation of the training was sound and embodied the best of German and British experience, adapted as necessary to suit American conditions and helium operation. Only one rigid airship has been in operation at a time and competitive effort has not been possible. Development would be faster if more rigid airships were in commission. The large cost of rigid airships and the fact that only one is now available, has put a heavy responsibility on airship personnel and has forced a cautious, conservative scheme of operation which while entirely sound has not as yet allowed the technique of rigid airship operation to develop to the full extent of its possibilities. This situation will correct itself when more airships and better facilities are available.

The facilities for rigid airship operation existing in the United States are not of the best and additional facilities are needed. Only two large sheds are available — Lakehurst and Scott Field. Unfavorable weather prevails at these places, especially at Lakehurst, for a higher percentage of time than at other sites which might be selected — for instance, the West Coast. Shortage of helium and meagre transportation and storage facilities have retarded operations at intervals. Several mooring masts have been erected at strategic points and are available but it has not been possible to use those masts remote from the shed base except at rare intervals.

A most important phase of operating airships is the perfection of arrangements and mechanical appliances for landing airships and handling them while on or near the ground and while placing

them in or taking them out of sheds. Important and promising work along these lines, as will be outlined later, has been done and is being done. It is safe to say the Navy Department has done more along these lines than any other agency. As a result we will be prepared to handle the larger airships now contemplated with no more difficulty and perhaps with less difficulty, than airships of the *Los Angeles* size. To mention only a few of the devices that show promise: the floating mast; fixed stub mast; mobile stub mast; mechanically operated docking trolleys; cars for supporting airships while moving in and out of the shed; mechanical aids in landing; artificial superheat device; remote control for hauling down winches; deck landing platform.

WATER RECOVERY APPARATUS.

With helium operation some means of accumulating weight during flight, as for example water-recovery apparatus, becomes a necessity. Basically, the apparatus is an air-cooled condenser which condenses the water vapor portion of the exhaust gases to water, the water being then returned to storage bags or containers inside the airship where it is available for use as ballast. Conflicting requirements of low weight, minimum head resistance, and perfect functioning as a condenser under the wide range of summer and winter flying conditions and over the various combinations of engines and engine speeds make the design of a satisfactory water recovery apparatus not an easy problem. Through a process of evolution there has been built an apparatus which, for the *Los Angeles,* works with reasonable efficiency. A recovery in water equivalent to 85-105 per cent of the (gasoline) fuel burned has been realized over a period of months. This has been sufficient to maintain the equilibrium of the airship in flight within such limits as to make it unnecessary to valve out helium in order to effect a landing.

The present type of water recovery apparatus is not entirely satisfactory. Its resistance is high and involves a reduction of about 5 per cent in maximum speed. It fouls easily and is difficult to clean. Certain parts, notably the cast aluminum headers and the aluminum tubes, require frequent replacement. The present weight of about .85 pound per engine horsepower is not unrea-

sonable but should be bettered. Attention is being devoted to using materials other than aluminum for the hottest parts of the apparatus and to mounting the apparatus close to the hull somewhat after the fashion of an airplane wing-type radiator.

But a water-recovery apparatus is not entirely an annoying appendage. It affords a means of accumulating during flight considerable quantities of water ballast. This is extremely desirable for a military airship which may be required to launch and recover airplanes during flight. It also offers a convenient source of heat on which to draw for heating living spaces. This is a problem yet to be satisfactorily solved, largely because not enough effort has been devoted to it.

With the probable future introduction of fuels other than gasoline, the water recovery problem will be affected somewhat, since the possible recovery of water depends upon such factors as composition of fuel, ratio of air to fuel, relative humidity, and temperature of the air. It appears that with either a heavy oil fuel or a hydrocarbon fuel gas, it will always be possible to obtain a reasonable percentage of recovered water. However, attention should be given to the matter of water recovery in selecting the fuels to be used.

ENGINES

The first considerations for airship engines are reliability and safety. If too few engine units are employed the failure of one unit has a serious effect on the speed of the airship. Very large single units involve concentrated loads which may introduce structural difficulties as well as force the adoption of excessively large propellers. On the other hand, if too large a number of power units is employed, the resistance of the airship may be seriously affected, and the number of men in the crew may be unnecessarily increased.

Considering these conflicting requirements, it appears the optimum size for an airship engine lies at 800-1000 horsepower. Propeller revolutions and propeller size are important, but through the use of gearing these problems can be handled independently of the engine if necessary. A propeller speed of 800-1200 R.P.M.

can be handled without going to excessively large propeller diameters.

Reliable and quick means for reversing propeller thrust are mandatory for airship work. This can be accomplished by reversing the direction of engine rotation; through the use of gears; or possibly through the use of reversing propellers.

Low fuel consumption is of importance. While the specific fuel consumption should remain steady over a wide range of power, the fuel consumption is most important at around two-thirds full power since this power will be that normally used for cruising. This leads to the suggestion that power plants for airships be compared on the basis of weight of engine plus weight of fuel required for 48 hours at two-thirds rated horsepower.

An air cooled engine might be adapted for installation in an airship and propositions to this end have been discussed many times. One scheme was to mount the engines by retracticable means so that the units not required at cruising speeds could be housed. But from an overall standpoint, having in mind the use of helium, it seems more desirable to place the engines inside the airship hull. Difficulties in engine cooling, unless water or steam cooling is resorted to, appear to exclude air cooled engines for positions inside the airship's hull.

These major requirements point at once to an engine of the solid injection type as the ultimate airship engine. Development of a light weight, high speed, oil-burning engine is a problem that has engaged engine designers and manufacturers for several years. Engines of this type are being fitted in one British airship that is approaching completion. These particular engines weigh between seven and eight pounds per horsepower, which is considerable more weight than is desirable.

Important development work is underway in the United States and it seems highly probable that satisfactory oil burning engines will be available in time to be placed in the second of the two rigid airships now building for the Navy Department. If this desirable end can be achieved a long step will have been taken towards increasing the safety of airships. The use of the safe gas, helium, requires the collateral use of the safest type of engine that can be developed. The fire risk from gasoline fuel is considered almost as great as the fire risk from hydrogen.

It appears probable that, even if slightly high in engine weight, the oil burning engine installation will prove to be more economical as to fuel required — both in weight of fuel consumed and cost of fuel.

FUEL GAS.

The recent development and use in Germany of a fuel gas in lieu of the customary gasoline, is an interesting, possibly important, event in airship progress and the success of the venture will be watched with great interest.

The idea itself is many years old. There is no particular difficulty about burning almost any hydrocarbon gas in the ordinary gasoline engine. To the Germans, however, belongs the credit of developing practical gas burning appliances adaptable to their engines and embodying changes in interior arrangements on the airship to permit the fuel gas to be carried.

The endurance of an airship is increased by burning a fuel gas in combination with gasoline. This increase may amount to as much as 40 per cent or more depending upon conditions. It is still a little puzzling why, with hydrogen already available in the airship, the Germans did not burn that gas in preference to valving it as the ship became lighter through consumption of liquid fuel. Hydrogen has been burned successfully in airship engines. Possible reasons for not adopting this procedure are, greater fire risk, more complicated combustion problems for the engine and more complicated operating technique. In adopting, as they did, a fuel gas of density approximating that of air, the Germans apparently had uppermost in their minds, besides the increase in airship endurance, the simplification in airship operation that would follow through leaving the equilibrium of the airship practically undisturbed as fuel is consumed, thus obviating the necessity, as under the old scheme, of shifting load to maintain the airship in proper trim or of valving hydrogen as the airship became "light." Note here that water-recovery is another answer to this problem.

An advantage advanced for fuel gas over hydrogen is that the range of explosibility of gas and air mixtures is less with fuel gas than with hydrogen. Thus the explosibility of hydrogen mixed with air has a lower limit of 4 and an upper limit of 74 — or a

range of 70; whereas a typical fuel gas might have a lower limit of 3 and an upper limit of 15 — or a range of only 12. Thus the range of explosibility for the fuel gas is about one-sixth that of hydrogen and it is therefore safer.

After experimentation with numerous gases and after considering density, heating values, condensation point, and possible deleterious effects on engines and fabric of the containing cells, the Germans chose as best for their purpose a modified "blaugas"—so-called after Dr. Blau, originator of the process. The gas is made by an oil cracking process and it was considered expedient to erect a special plant near the airship shed for manufacture of the gas. This was a prudent move because while the gas is not expensive at its source, it becomes very expensive if it must be compressed and transported. Some difficulties were experienced with the operation of this fuel gas plant which resulted in delays in the *Graf Zeppelin's* arrival in the United States. Difficulties are likely to be encountered in drawing off a uniform gas from a container of "blaugas," since the gas is made up of a number of constituents and is consequently not stable.

Several months ago the Bureau of Aeronautics was requested to locate in this country a gas having the required characteristics in order to replenish the *Graf Zeppelin's* fuel on her arrival in America. Our first efforts were abortive, because we tried to locate a "blaugas" duplicating that planned for use in Germany. Several "blaugas" samples were procured but they were unstable, uncertain and unsatisfactory. We turned then to the recently created and rapidly growing natural gas industry in the United States, and there found a satisfactory, and cheaper substitute gas — virtually a vaporized gasoline. The methane-ethane-propane series is being extensively processed for industrial uses at various points and offers attractive possibilities as a source of "fuel gas" for arships in future. Indeed, ethane has a density of 1.03 and other characteristics that are satisfactory. Commercially pure ethane would serve nicely but was found to be expensive. In one town in Oklahoma citizens are burning in their stoves at a price of fifty cents a thousand, just the sort of gas that is required.

While cheap at its source (and cheaper here than in Germany), a fuel gas will prove expensive if it must be compressed and trans-

ported. Going to the heavier gases in the series, as propane, density 1.5, we have a gas that may be "shipped as liquid; burned as gas." This results in a tremendous saving. The airship could burn a gas of density 1.5 but would lose some of the desirable results that follow from a density of around 1.0. However, propane can be diluted with hydrogen, or coal gas, procured near the airship base, to bring the mixture to the desired density, and thus save considerably in transportation costs. If we are ever to adopt the use of fuel gas in our airships, these and similar questions must be looked into carefully and the best solution found. One thing is certain, however, there will be no difficulty in finding a satisfactory and cheap fuel gas from among the wide variety of natural gases available in the United States.

On first glance it would appear that a combination of helium as a lifting gas together with a fuel gas would be an ideal combination. The increase in airship endurance and the smaller quantity of high priced helium that is necessary are attractive. The combination should prove economical. However, complications, particularly as to interior arrangement, are involved. It is too soon after the first real use of fuel gas in airships to form final opinions as to the merits of the scheme. The expected introduction of oil burning engines may change ideas with reference to the utility of the fuel gas scheme. For commercial operation of airships, it does appear that a combination of helium, fuel gas and a small amount of water recovery apparatus would prove to be the most economical combination available at the present time.

HELIUM.

Helium, as we all know, exists in certain natural gases in the United States. The helium content varies from a small fraction up to around two per cent and it is profitable to extract this helium if it exceeds about 5/10 of one per cent. The method of extracting the helium from the natural gas will depend upon the physical properties of the constituent gases. The general basis of methods used for both extraction and purification of helium is the low liquifying temperature of helium compared to the various other gases.

In the past airship operations have been handicapped by insufficient supplies of helium but since a year ago we have been able to obtain an adequate supply for operations and are gradually accumulating the quantity that must be available when the two new airships now under construction are ready to be inflated. There is no shortage in the natural supply of helium. From reliable geologic reports, it is well established that from one field alone twenty million cubic feet or more of helium per annum can be extracted for the next fifty years — and this without touching the so-called Helium Reserve set aside in Utah. The Bureau of Mines, Department of Commerce, as the Governmental agency now charged with helium conservation and development is about to enter and establish a plant in a virgin field, where the quantity of helium available is enormous. This is in accord with appropriations granted by the last Congress for this work.

Aside from the Government's production of helium, the matter has attracted interest from commercial firms. A little over a year ago, the Navy Department was approached by a firm with a definite proposition to sell helium on the same basis as any other commodity. A contract was made and in six months this firm had erected a plant and was producing helium at a price somewhat less than that obtaining in the Government plant. It is pointed out, however, that this rapid establishment of a plant and commercial production of helium could not have occurred had it not been for the pioneer work of the Government in helium production. In this work the Navy Department played an active and leading part until three years ago, when control over Government helium plants passed to the Bureau of Mines.

There is growing up in this country a moderate demand for helium in various lines of activity. Some 200,000 cubic feet is used annually for other than aeronautical purposes. It plays a useful and important role in the treatment of "bends" from which divers sometimes suffer; it is used for various medical and other scientific researches; some is used in radio tubes; in housings for high speed gyros; and a considerable quantity is used in toy balloons.

When production of helium first started, seven years ago, the costs were high. Eliminating the very high experimental cost of

the first few thousand cubic feet, we can say the first helium produced in quantity (1921) cost approximately 25 cents per cubic foot. Costs have now been brought to around 3.5 cents per cubic foot. They have gone as low as 2.4 cents at one period. There is every prospect that in a very short time — say one to two years — the cost of helium will be around 2.0 cents per cubic foot.

Helium as a lifting gas for airships has both advantages and disadvantages. It is probably significant that those who are loudest in disclaiming helium are those who do not have access to a supply of the gas. A case can be made on economic grounds alone that helium operation of airships, despite repurification costs, transportation costs and storage costs is about on a par with hydrogen operation. Needless to say, without water recovery apparatus (or possibly the partial use of fuel gas) such a favorable comparison would not be attainable.

Helium does cause an important reduction in cruising range, due to the fact that its "lift" is less than hydrogen and this reduction in lift cuts down the only reducible item in the airship's loading schedule, viz., fuel. The range of a helium airship may be 30-40 per cent less than that of a corresponding ship filled with hydrogen. If we inject the possibility of using fuel gas, comparative figures become more difficult and confusing, but it is clear that using helium and hydrogen in corresponding ways, the helium airship will have a smaller range. It is the price we pay for safety. Helium forces us to use water recovery, but as pointed out, this complication has some important compensating advantages. Helium involves a modified and more difficult technique of airship operation. The desire to economize on helium has made it imperative to keep a more careful check on gas losses. Losses that escaped unnoticed under hydrogen operation must be carefully analyzed and efforts made to reduce them.

From time to time helium must be re-purified. This necessitates a re-purification plant at the airship station, and the costs of re-purification and the helium losses incident thereto, must be reckoned with. These re-purification costs have in the past run somewhat under a half-cent per cubic foot. How often re-purification is necessary will depend on circumstances but it will be found

profitable to re-purify before the purity falls to 85 per cent, and this will require a complete re-purification probably every four to eight months. It should be noted in this connection that helium seldom if ever is available at 100 per cent purity. The maximum purity that can be realized practically in the airship is of the order of 95 per cent for a freshly "re-purified" airship.

HELIUM TRANSPORTATION.

After helium has been produced its transportation and storage become problems of first magnitude. The normal method of shipping gasses of similar character has been in steel cylinders or bottles of 2600 cubic inch water volume size, conforming to Interstate Commerce Commission Specifications 3-A and Bureau of Explosives Regulations. These cylinders hold about 176 cubic feet of helium at 1800 pounds pressure. Each cylinder weighs about 120 pounds, and approximately six hundred (containing about 100,000 cubic feet of helium) can be loaded into an ordinary box car for shipment, making a carload shipment weighing some 40 tons. On this the freight charges from Texas to the Eastern seaboard may amount to $1200, or $12.00 per thousand cubic feet of helium. Besides this the empty cylinders must be returned, involving a freight charge of about $600.00 per carload.

Enormous quantities of these steel cylinders were purchased by the Army and Navy for War purposes. A number of them have been fitted with double seated valves in lieu of the ordinary single seated valve in effort to cut down leakage losses, and when so equipped have perforce been used for shipping helium. However, this method is strikingly uneconomical.

In effort to reduce transportation costs both in freight charges and in handling charges at either terminal, there was developed several years ago by the Navy Department a tank car which would transport approximately 200,000 cubic feet of helium at 2000 pounds pressure. Aside from the saving in labor of loading and unloading the small cylinders, the tank car is given far more favorable freight rates loaded, and for return in empty condition there is no freight charge. Upkeep costs on the car have not been appreciable. By the use of such cars the inclusive freight cost

of transporting helium from Texas to Lakehurst is cut to less than $4.00 per thousand cubic feet, as compared with about $18.00 per thousand by the small cylinder method.

The type of tank car that is now in service comprises three large cylinders about four and one-half feet in diameter by about thirty-nine feet long. Each cylinder is equipped with valves and safety devices. The cylinders are so large they must be made by a forging process which is costly and is a process only a few concerns are equipped to handle. The result is a car that is satisfactory and economical in operation but which is enormously expensive as to first cost. The three cars of the type in existence, one owned by the Navy and two by the Army, have cost in the neighborhood of $98,000 each.

A study was undertaken to determine whether it was not possible to produce a car equally satisfactory and at a much lower first cost. As a result a design has been worked out for a tank car which uses about thirty seamless drawn pipes of moderate diameter instead of three large cylinders. The mounting of these pipes in a manner that will stand rough freight service was a problem, but it has been solved with the result that the new type of car will weigh only slightly more than the three-cylinder type and will transport the same quantity of helium. The first of these new type cars is under construction at a cost slightly under $60,000 and there is good prospect that future orders can be placed at a lower figure.

Firms that produce welded steel products of comparable nature and size have been interested in the problem and there is hope that in the near future a satisfactory type of welded steel cylinder will be available to help in still further reducing tank car costs. As yet the Bureau of Explosives has not sanctioned the use of a welded container for high pressures but with the rapid strides being taken in perfecting welding processes, it is to be hoped that approval will eventually be given to welded construction for transportable containers for helium if not for other gases.

These helium tank cars are both helium transport and helium storage. They very greatly increase the mobility of the helium supply. The saving in freight costs alone will pay for a car in a few months. Besides, there is the very large saving in handling

charges at each end. For these reasons a comparatively large fleet of such cars is desirable. The cars can be procured almost as cheaply as can immobile containers of like character.

HELIUM STORAGE.

Since helium is not a manufactured product and since it is desirable and economical to operate the helium production plants at a steady rate we are confronted with a helium storage problem. Were we able to produce quantities of helium as needed, it might prove feasible to leave the natural gas containing its one or two per cent helium in the ground, drawing on it only as needed. To as large a degree as practicable, this is being done, but there must be on hand at each airship station a reserve supply of helium. How large this reserve supply should be is at present a matter of judgment. A storage capacity at least equal to the volume of airships operating from a given station is desirable. The question then becomes, what is the best form for this storage capacity; gas holders or gasometers of the ordinary city type; high pressure containers (above 120 atmospheres); or moderate pressure containers (around 20 atmospheres)?

It is convenient to have a certain amount of gas holder space available, but in general it is to be regarded in the nature of temporary storage; for impure gas before repurification; and to serve as a reservoir facilitating the operation of gassing the airship. At least two such gas holders, each equal to, or larger than, the largest gas cell in the airship, are desirable.

The remainder of the storage space can very well be containers for holding the gas under pressure. As long as the war supply of 2600 cubic inch steel cylinders lasts they, of course, will serve, but sooner or later they must be augmented by new pressure containers.

A survey was made to determine the cheapest container that could be obtained in the market. It requires about the same weight of container to confine a given quantity of helium, no matter what pressure is used. However, to store helium at 120 atmospheres or above involves compression costs and containers of a rather expensive type. At an airship station ample space is available and by going to somewhat lower pressures, say around

20 atmospheres, it seems practicable to adopt a type of container that is cheaper and more readily available in the market. The results of the survey of the market is summarized in the following table.

APPROXIMATE COSTS PER CUBIC FOOT OF VARIOUS TYPES OF HELIUM CONTAINERS.

Type	Storage Pressure, Atmospheres.	Cost per cu. ft. of dischargeable free gas volume.
Mobile:		
Present style tank car	140	$0.50
New style tank car	140	0.31
Fixed:		
Large forged cylinders, rough finished	140	0.28
Seamless drawn cylinders as used on new style tank car	140	0.21
Welded tanks, boiler size	10.	0.19 to 0.24
Commercial riveted tanks, boiler construction, welded for tightness	24.	0.15
Gas holder, telescoping city gas plant type	1.	0.10 to 0.12
Small drawn cylinders, 176 cubic-feet size	120	0.09
Commercial riveted tanks, boiler construction, not welded (of doubtful utility)	14.	0.08
Welded tanks, made from long welded pipes, about 2 feet diameter	34.	0.08

NOTES:

(*a*) Costs of necessary valves and manifolds, foundations, and shelter are not included.

(*b*) Costs are approximate but indicate relative prices for storage containers of the several types.

(*c*) The value of the gas remaining in a low-pressure type of container at atmospheric pressure after discharge is complete needs to be taken into account.

HELIUM LOSSES.

Helium losses occur in several ways. There is a loss in transportation; there is a loss whenever helium lies in storage in containers; there is a loss whenever helium is re-purified; there is a loss by diffusion when helium is in use in airships. There is a loss, or expenditure, whenever in course of operation it is necessary to valve helium. There are occasional accidental losses which it appears impossible entirely to eliminate. Based on past experience, it has been estimated that operating a rigid airship of the *Los Angeles* type will require one to one and one-half ship-volumes per year. This, however, depends upon the condition of the gas

cells. With good gas cells it will be less. It is difficult to estimate how large the losses on account of gas cells (i. e., diffusion losses) will be, but they will amount to approximately 60 per cent of the ship volume per annum, and an estimate of 5 per cent per month should be reasonable. Transportation loss is small, about 1 per cent, and this includes some inevitable discrepancies in delivery and reception data and records. Storage losses, depending upon the type of container in which stored, will be about ½ to 1 per cent per month. Re-purification loss is 7 per cent to 10 per cent of the impure gas supplied for re-purification. The operating loss through valving is impossible to estimate in advance, but it is a small figure. Accidental losses have been very small in the past — not over 2 per cent per annum.

Some of these losses are based on the time element; some are based on quantity of impure gas; some other, as valving losses, are arbitrary. It is therefore difficult to give an overall estimate of losses. As an approximation, however, the total loss per month should run about as follows:

Transportation — 1 per cent of helium produced.

Storage — ½ per cent of helium in storage.

Re-purification — ¼ × 10 = 2½ per cent of ship volume. (Estimated on repurifying a ship volume each 4 months.)

Diffusion — 5 per cent of ship's volume. (Cells in fair to good condition.)

Valving, Operations, Accidental Losses — Small.

GAS CELLS.

No important parts of an airship are in need of improvement more than are the gas cells. They are deserving of the most careful thought and attention, since they are a vital and at the same time a most delicate part of an airship. In weight, gas cells represent some 10 per cent of the dead weight of an airship — almost as much as the power plant, and approximately a third as much as the structural weight. In cost the gas cells may represent 10 per cent or more of the cost of the airship. They require considerable hand labor and a long time to manufacture. Each cell is tailored to fit a certain position in the airship and a duplicate cell is desirable as a spare for each position. If a set of cells in service lasts

only three years it will be seen how important it is to increase the durability of cells.

A single cell may contain 600,000 — 900,000 cubic feet of gas; and may comprise some 6000 square yards of fabric weighing 4 to 6 ounces per square yard or a total weight of a ton. Such a cell makes quite a large bundle when properly folded or rolled. It must be inserted into the airship through a small opening in the lower hull covering; and "floated" or otherwise hoisted into position. To accomplish this rather delicate operation without injury to the cell requires great care. The rough and ready methods of circus hands in spreading the sections of their tent can not be used. With helium operation it is occasionally necessary to deflate a cell. This is a hardship on the cell and is also a delicate operation.

Various kinds of fabric for manufacture of gas cells have been tried in the past both in the United States and abroad. Nearly all fabrics regarded in the past as satisfactory have utilized goldbeater's skins as the principal impermeable membrane. These parchment like skins come from the caecum or blind gut of oxen, sheep or hogs, and are tedious and expensive to handle. Over a million skins might be required for a set of cells for a large airship.

For some years past the Bureau of Aeronautics, Navy Department, in collaboration with the Bureau of Standards, has supported an extensive investigation into substitutes for the expensive goldbeater's skins. Gratifying progress has been made but there still is room for improvement.

Basically, a gas cell fabric consists of the following constituents:

(*a*) Cloth (usually cotton),

(*b*) Foundation for gas-retaining membrane or film (and adhesive, if one is required),

(*c*) Gas retaining membrane or film,

(*d*) Water proofing varnish (may or may not be applied).

A satisfactory cloth should have a high strength/weight factor; should be of a balanced construction; and should have a finish that will take satisfactorily the foundation adopted for the gas retaining layer. The cloth generally used weighs about 2 ounces per square yard and has a breaking strength of 40 pounds per inch with in warp and fill directions,— or in other words, it has a strength/weight ratio of 20.

The foundation for the gas retaining membrane has usually been rubber or some form of adhesive. If rubber has been used, the adhesive has been an addition. The rubber is applied by a series of passes through rolls. This is neither a long nor an expensive process, but the life of the rubber layer under service conditions is not all that it should be, in spite of efforts to have the rubber intentionally under cured.

It is the gas-retaining layer that is the meat of the sandwich. Numerous experimenters have tried various substances in effort to get away from the costly goldbeater's skins. Ninety-nine per cent of the suggested means fail when samples are subjected to the standard test of "wrinkling" and requiring them thereafter to show a permeability to hydrogen, at a pressure of 30 millimeters of water, less than 1 liter of hydrogen per square meter per 24 hours. In addition, a test involving soaking in water should be used with certain fabrics. Some of the fabrics which showed promise in laboratory tests are too difficult or too expensive to manufacture; do not lend themselves to easy seam making; or do not stand up under exposure and service tests.

Next after the gas retaining layer usually comes a coating of varnish, paraffin applied hot, or some equivalent layer designed to act as a protection against ingress of moisture or egress of some constituent from the fabric. As a rule this waterproofing layer has been applied only to the treated side (i. e., inside) of the fabric, but there is no reason why it can not be applied to both sides of the cloth.

Various alternative constructions for fabrics have been tried, such as using two layers of cloth in true sandwich fashion. This is done with that other class of very heavy rubberized fabrics from which balloons and envelopes for non-rigid airships are made. It appears to be impracticable for a fabric that must not exceed six ounces per square yard in weight.

The investigation into substitutes for goldbeater's skin, conducted at the Bureau of Standards, was started in 1917. It has been a long, tedious, development and the end is not yet. Hundreds of samples have been tested and the records are voluminous.

One of the first phases of the work was an investigation into

the factors affecting permeability of rubberized fabrics. As a result, considerable literature on this subject is now available.

Another phase of the work concerned itself with the factors affecting permeability of varnished and similarly treated fabrics either with or without the use of rubber in combination. This phase covers a wide field and includes oiled cloths of various descriptions, paper products, and miscellaneous fabric constructions tested with a particular view to their adaptability as gas retaining media. It was found that an increase in the rosin-glycerol content in a varnish resulted in a substantial decrease in permeability. The addition of aluminum powder to varnish reduced permeability. This led to a trial of aluminum foil. Permeability was reduced to a favorable figure but such fabrics can not withstand the mechanical handling to which a gas cell is subjected. At one time tung oil varnish appeared to give promise and it was exhaustively tried in various combinations. It is satisfactory for a while but does not stand up in service.

Gelatin in various combinations was tried since it is similar to the substance of which goldbeater's skin is largely composed. Films of casein; films prepared from asphaltum and rubber; the so-called marine glues; and films of albumen were all tried. They all became brittle and harsh after a short while.

Another phase was concerned with cellulose products. Cellulose acetate and nitrate dopes (similar to coatings used on the outer covering of airships and airplanes) were found to have relatively high permeabilities. Of the cellulose products, sheet cellophane, and the corresponding viscose and viscose-latex fabrics, have all been found to yield films and fabric of low permeability.

Briefly stated, viscose is a viscous solution of a form of cellulose obtainable from wood pulp, grass fiber, cotton or other vegetable fibers by a series of chemical processes. In various forms it finds use in artificial silk and allied products. Cellophane is substantially viscose in sheet form. Viscose-latex is the prepared viscose to which has been added a certain proportion of rubber latex (i. e., the sap of the rubber tree to which a preservative has been added).

Much thought and labor has been expended in trying to make a durable fabric out of these basic products. Curiously enough it

was a suggestion that cellophane might be used for gas cells that appears to have started the extensive investigation into a variety of substances. Cellophane and viscose products were at that time practically unobtainable in the United States in the weight required. It is only within the past few years that these products have been produced in marketable quantities in the United States. While cellophane is an every day sight as a wrapping for candy and similar goods, its manufacture is still closely guarded.

The early efforts on viscose coatings were failures. When exposed the fabrics became brittle or otherwise went to pieces in thirty to sixty days. The addition of a plasticizer such as glycerol was clearly indicated and proved so beneficial that it must now be classed as a vital part of the production process.

Sheet cellophane has been applied with some success, by means of both hide glue and rubber cement. It is difficult to produce a satisfactory fabric regularly and in large pieces. The operations of laying the cellophane are at present hand operations, thus increasing the cost of workmanship. On the other hand cellophane is available in unlimited quantities as a commercial product and at a relatively low cost.

Viscose and viscose-latex mixtures have been applied to both plain and rubberized cloth. While some problems still exist in applying the viscose products on a production basis, the method seems well adapted to commercial production. The process is similar to and not much more laborious than spreading rubber on cloth. At its present stage of development, however, the process is a very sensitive one and success depends largely on proper drying temperatures, proper ventilation, age of viscose, and such matters that are difficult to standardize. The viscose-latex type of gas cell fabric as it is known today comprises essentially a 2 ounce cotton cloth, spread or fastened with a 0.6 ounce coating of rubber; a sizing coat of a gelatin glue mixture; the gas retaining film of about 1.3 ounces of the viscose-latex mixture applied in several coats; and finally a coating (optional) of a flexible waterproof varnish. Thus the finished fabric has a weight of about four and one-quarter ounces per square yard.

Recently a complete cell of viscose-latex fabric was manufactured and placed in service. After five months it is still stand-

ing up well but it will be some time yet before conclusions may be formed as to its serviceability. It looks promising. Minor difficulties have developed but these are believed attributable to local conditions and not to any basic troubles with the fabric construction.

Another cell has been built of sheet cellophane and this also will be given a service test.

The future progress of the research into substitutes for goldbeater's skin will likely be along the following lines: improving viscose-latex and cellophane types of fabrics, their manufacturing technique, production methods, seaming methods; improving the present rubber foundation used with these fabrics and study of the possibilities of using substances other than rubber for this purpose; studying possible materials which do not require the use of hygroscopic, water-soluble plasticizers such as glycerol; endeavoring to develop a more satisfactory water-proof varnish or lacquer suitable for interior, and possibly exterior surfaces of gas cells.

Admitting that the investigation into substitute fabrics is far from complete, we can only summarize in a general way the status and availability of fabrics for gas cells as they stand today. Thus we have the following more or less distinctive fabrics, arranged approximately in the order of their cost per square yard if produced in the United States:

(1) Cloth — rubber — single layer goldbeater's skin — varnish (American type).

(2) Cloth — glue foundation — two ply skins — varnish (German type).

(3) Cloth — rubber — cellophane sheets — varnish.

(4) Cloth — rubber — viscose — latex spread — varnish.

(5) Rubber — cloth — thick layer of rubber — hot applied paraffin.

As to relative durability it is impossible to give any real comparisons. Almost any of the types should last three years in service. A sample of number (4) was satisfactory after 40 months exposure under cover on a roof. However, durability is the prime requisite of a satisfactory gas cell fabric. Heretofore, high strength/weight ratio has been stressed. If by going to slightly

heavier construction the durability of the fabric can be enhanced it will be one case of where the increased weight is justified.

Two years ago, in an emergency, some gas cells were obtained for the *Los Angeles* of a cloth-rubber-paraffin construction according to type 5. This is perhaps the cheapest type of fabric that can be obtained. It is heavy but is capable of giving fair service. The specifications under which the fabric was manufactured were hastily drawn and unquestionably the type of fabric can be improved.

In this connection it may be noted that the relative permeabilities of various media and fabrics to hydrogen, helium, and water vapor are approximately of the following order:

Substance or fabric	Hydrogen	Helium	Water Vapor
Rubber	100	65	150
Goldbeater's skins (alone)	100	120*	.....
Cloth—Rubber—Goldbeater's skins—Varnish	100	80	.....
Viscose—Latex	100	80	.....

* This figure is open to question.

OUTER COVER.

The fabric hull covering of a rigid airship is a favorite target for criticism. Eighty per cent of the outer cover now on the *Los Angeles* is the same cover that was installed nearly five years ago. This is even better durability than was anticipated. Repairs have of course been required. Re-tautening and re-doping has been necessary but no general renewal of outer cover has been made.

The basis of the outer cover fabric is cotton cloth, somewhat heavier and stronger than that required for gas cells (finished weight about 6 ounces per square yard). The cloth is sewed into panels; laced into position; tied down to prevent flapping; and doped in the same fashion as an airplane wing. At one time it was customary to pre-dope the outer cover before installation, but it is now considered best practice to apply all the dope after the cloth is in place as this gives better tautening effect. A loose cover can have a considerable adverse effect on the airship's speed and may even reduce the safety factors in the ship.

The use of aluminum powder in the last coats of dope has an important improving effect on water proofing, reducing super-

heating effects, and on general durability of the fabric. Aluminum was first used in the doping schedule for the *Shenandoah;* was required in the *Los Angeles* and has since become standard for airships.

Probably metal covering in some form will be developed for airships. When it does come it will probably be as an adaptation of metal to a general type of rigid airship structure rather than through a new theory of design based fundamentally on the use of a metal hull. As known at present, a metal hull covering is not suitable for general use on a large rigid airship because it is heavy, can not be smoothly applied, and unless kept under pressure, the thin skin contributes practically nothing to the strength of the ship and therefore becomes a real burden. Metal covering can and will be used in certain special locations.

For immediate improvement in hull covering for rigid airships, we must look to improved cloth. The strength/weight factor is of more importance than with gas cell cloths. Since it is not necessary to spread a thin film of rubber over the outer cover, we do not require such a smooth, uniform weave. It may be possible to get increased tear resistance, if not increased strength/weight factor also, by the use of larger threads, special weaves such as herringbone, basket weaves, etc. An investigation along these lines is underway.

AIRSHIP HANDLING EQUIPMENT.

The large airship which is so easily handled while in free flight becomes a problem whenever restrained by contact with the earth. The ground-handling of these airships is unquestionably a difficult and involved problem, but it can be solved. Progress towards solution has been gratifying, but considerable yet remains to be done.

While the principles of handling airships are much the same as those for handling surface vessels, in airships we have a third dimension. We also have to deal with wind, gusts, eddies which may have an almost instantaneous effect on an airship and which make it necessary to keep the airship constantly under control and to anticipate if possible the changes that are likely to occur. The

analogy of bringing a sailing vessel to her dock with canvas spread is a crude one but conveys some idea of what airship handling may involve.

Patent Office files contain many patents on airship handling equipment. A perusal of these and other literature leads to the conviction that there is very little new in regard to airships. However, most of the devices that have been proposed are either conceived without regard to the practical side of airship handling or are in themselves so complicated as to be impractical. While the large dimensions of airships often force the adoption of large, awkward looking equipment, a cardinal principle in developing such equipment is to keep it simple. There is no substitute for actual experience in designing and actually trying out various equipment.

The location of an airship base, the orientation of the shed, if there be one, and the type of shed, all have important bearing on the problem of handling airships. The base should be chosen where meteorological conditions are favorable. The shed, if of the fixed type, should be oriented so that the cross wind component will be a minimum under conditions when it is likely the airship will be docked or undocked.

The largest single item of equipment on the airship base is the shed. We can distinguish several types, as follows:

Fixed — steel framework.

Fixed — reinforced concrete.

Rotatable — pivot near center; steel frame; turns on track.

Rotatable — pivot near center; steel frame; floating in pond of diameter equal to length of shed.

Rotatable — pivot near center; steel frame; flotation through one or more annular moats.

Rotatable — steel frame; floats in pond of diameter equal to twice the length of shed; door at one end only.

Circular — steel frame; center post; six or more doors; holds two or more airships which can be rotated inside the shed.

Except in the possible case of the last mentioned type it may be assumed that future sheds probably will house only one airship.

Without question a rotatable shed is highly desirable and is the ultimate solution. However, we are considering a structure that

must be over 900 feet long and have a clear cross section 190 feet or so in diameter. No structure so large has ever been built as a rotating structure or even as a floating structure. It can be done but will be expensive. We are interested in keeping costs low. Therefore, it seems probable the airship sheds built in the immediate future will, on account of economic expediency, continue to be of a simple, fixed type, and this type will be assumed in the remainder of this discussion. Much can be done in reducing the cost of sheds and their auxiliary equipment.

There is nothing particularly novel about a floating shed. The first Zeppelin shed was a floating type. It was modified to incorporate a floating barge on which the airship was landed and secured before housing the barge and airship. The Navy's first attempts with small non-rigid airships at Pensacola made use of a floating shed. It does not appear, however, that any of these floating sheds developed the rotating feature as completely as might have been done. Many improvements as to detail have been suggested, and when the time arrives an improved type of floating shed can be designed.

Not enough attention in the past has been devoted to selecting a design of shed and doors that will reduce wind resistance and disturbing eddies to a minimum. Consideration of these factors benefits not only the airship but allows less material to be used in the shed itself.

There are two general situations with reference to wind: one a wind parallel to the shed axis; the other, a cross-wind. Assuming the shed has two doors, there are two choices, to windward or to leeward. We have also conditions of "stern out first" or "bow out first." Thus a choice from among several conditions must be made. The most conservative practice has been to use the leeward door on the theory that in case something goes wrong the airship will be carried away from the shed. But on the leeward side of the shed there is always turbulent air which may cause more trouble than a wind of known direction. Around every shed or building we find peculiar wind conditions. There is a down falling current at the leeward end of a shed, which extends out a distance about equal to the height of the shed, and curling inwards forms a back draught into the shed. The doors, if in the

wind path, create eddies on their leeward side. Thus there is a danger zone to leeward of the shed structure. This zone can be minimized through careful shed and door design.

The problem of landing and handling and docking a large airship has several phases. We can distinguish between:

(1) Landing on the field.

(2) Mooring to a mast, i. e., a "flying moor."

(3) Towing the ship across the field as for instance towards the docking rails or to a mast.

(4) Swinging airship to center her between docking rails or to point her fair for the take off.

(5) Hauling airship into or out of the shed, using side docking rails and trolleys, or substitutes therefor.

(6) Docked in a shed.

(7) Riding to a mooring mast.

(8) Taking off from the field.

(9) Taking off from a mast.

(10) Special situations as, for instance, landing on the deck of an aircraft carrier; towing; and refuelling at sea.

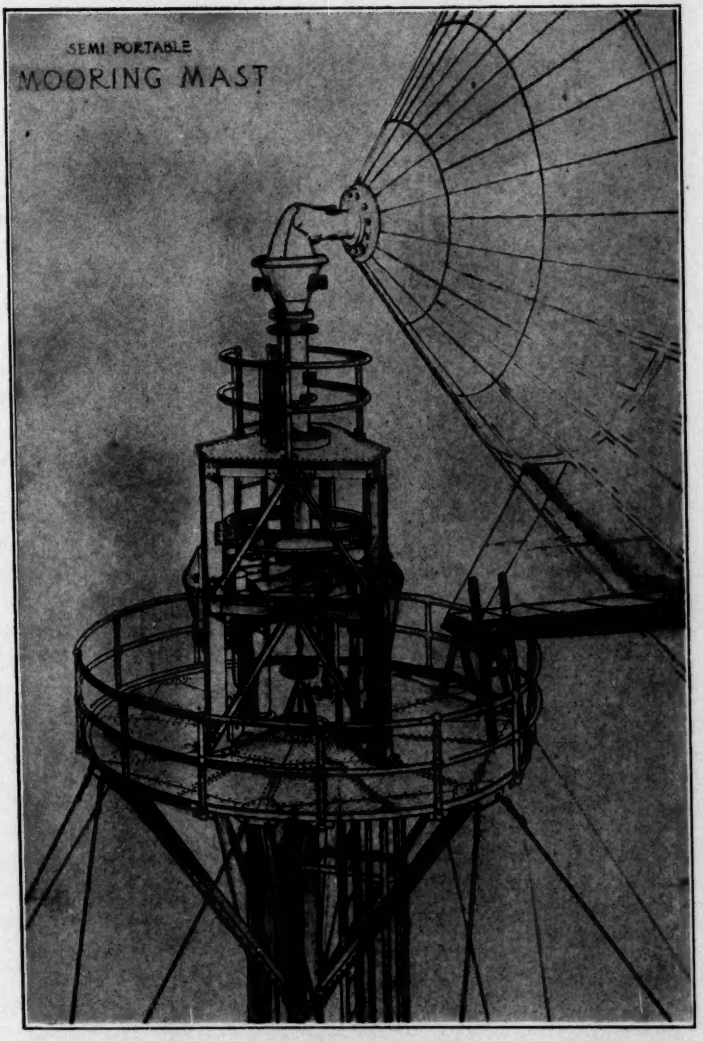
Several fundamental principles have been learned through experience. One is that the extreme bow or nose of an airship is the proper place for mooring attachment and is likewise the best point from which to tow the airship around the field. The airship watches into the wind without any difficulty when held at this point, and the bow, from the nature of its construction, is enormously strong. Attempts to tow from some other point, as for example the forward point of the control car, meet with but indifferent success on account of the uncertain way in which the ship watches. Another point is that a side wind can exert considerable rolling moment and therefore it is desirable that restraining side forces be applied so that the resultant acts approximately through the axis of the airship. When moored the ship should swing freely and, whenever practicable, the airship should be permitted its natural desire to head into the wind. Attempts to haul her across wind involve considerable forces. However, the airship must on certain occasions be handled when there is a cross wind component and this can be done, as for instance when the

airship is between docking rails. Here the athwartships lines should be carefully handled; should form a part of a determinate system or should have provision for equalizing forces; and should be arranged with quick release devices.

The problem of landing on a field is not particularly difficult with an intelligently handled airship, and provided an adequate ground crew is available to grab handling lines and bring the ship under control. However, the maneuver is more difficult with a helium filled airship that is frequently "light" by several tons, than with a hydrogen filled airship where this light condition can readily be neutralized by valving out gas. As with surface vessels, some officers will develop into better "airship handlers" than others.

In discussing the problem of mooring to a mast we are at once involved in the advantages and disadvantages of high and low types of masts. A "flying moor" can be made to a high mast in a few minutes time and with the assistance of only a handful of men. The airship hovering above and somewhat downwind from the mast drops a main hauling-in cable and two side steadying or yaw guys. These are coupled to similar lines on the ground. The ship is hauled in by the main cable and is steadied and prevented from over-riding the mast by the yaw guys. By a modification of the method a similar maneuver is executed in mooring to the floating mast on the U. S. S. *Patoka*. The time for mooring to the *Patoka* mast has run from seventeen minutes to an hour with an average time of around thirty minutes.

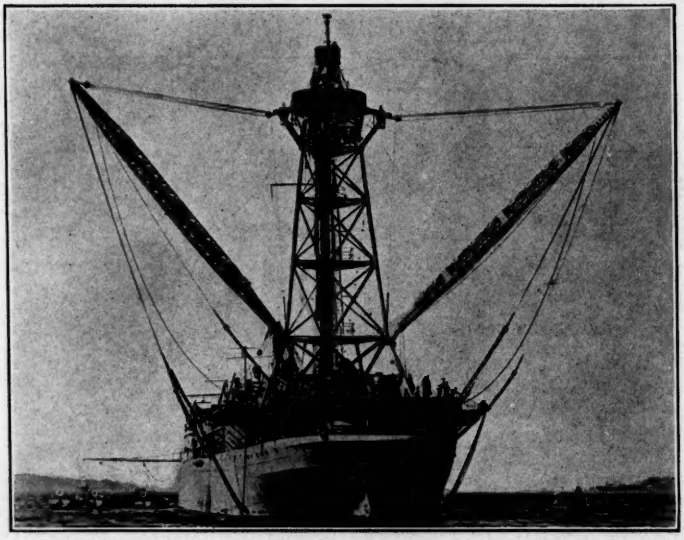
At a high mast, the airship can take an angle of eight to twelve degrees, depending upon the height of the mast, before any part of the airship touches the ground. This angle can be kept to within two or three degrees as a rule. However, constant and careful attention to the trim of the airship is required while the airship is riding to a high mast. Unexpected cold or warm strata of air, or gusts, may cause the airship to incline up or down and shifting weights to trim the ship are necessary. A "mast force indicator" showing what force the ship is exerting on the mooring point furnishes valuable information to the officer of the deck. In addition, a tail drag made up of old chain cable plus artillery wheels to facilitate dragging over the ground, serves in a limited



(*Navy Photo.*)

FIGURE 4.

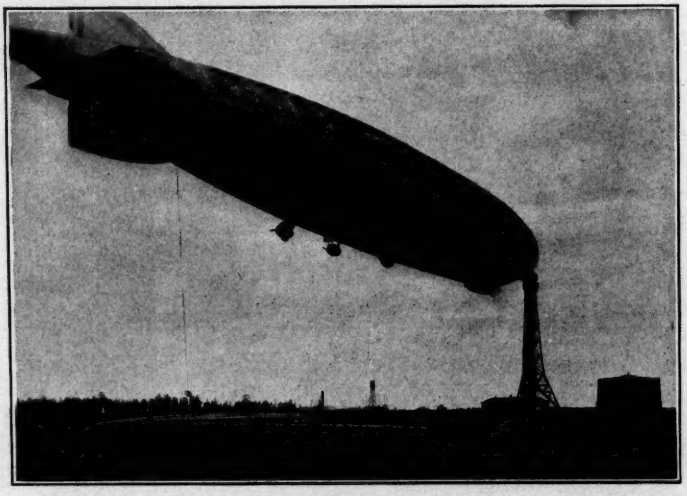
Sketch showing typical lay-out for the head of a mooring mast (high type). The head of a stub mast is similar but simplified. A cone on the airship is held firmly in the mast cup by three latches. The mast cup, mounted in gimbals, may be tilted to facilitate mooring; and is then secured in an upright position.



(Navy Photo.)

FIGURE 5.

Mooring mast and yaw booms, U. S. S. *Patoka*. Due to the fact that the position of the yaw booms is fixed, it is necessary for the *Patoka* to steam slowly into the wind during the mooring operation. In future it will be desirable to arrange the yaw booms to rotate; thus making it possible to point them down wind with the *Patoka* anchored. Since this photograph was taken the height of the *Patoka's* mast has been raised 20 feet to 140 feet above water line.



(Navy Photo.)

FIGURE 6.

U. S. S. *Los Angeles* moored to the 168-foot mast at Lakehurst. The tail drag may be seen just forward of the fin. The airship shed is in the background.

degree to compensate for changes in buoyancy. As the ship tends to rise, it is required to pull up a gradually increasing weight of tail drag, which, of course, checks the rising tendency. As the ship descends a reverse cycle is carried out. For the floating mooring mast on the U. S. S. *Patoka* a similar tail drag made up of floating drums is used. As the ship swings to the wind it must pull the tail drag around with it and with a mast on shore this is objectionable because of the pull the tail drag exerts on the ship. It would seem, however, that the tail drags that have been used are relatively crude affairs and that considerable improvement in tail drags and their attachment to the airship could be made.

The effort to shield the airship from the causes of up and down motion while moored, led to the idea of a short or "stub" mast only high enough (about 60 feet) to reach to the ship's axis or bow mooring point. It seems to be fairly well established that near the ground "vertical gustiness" of the air is less, and consequently the airship is less disturbed when riding to such a low mast — particularly if the mast can be located in a saucer-like depression or be surrounded by trees to give some degree of natural protection. However, carrying out the maneuver of mooring to a "stub" mast is more difficult than with the high mast. There is danger of some part of the airship striking the ground unexpectedly before the maneuver is completed and the airship is secured in the riding position. With an ample ground crew, the maneuver can be made but the idea in developing handling methods is to get away from using man power. As yet, a stub mast with complete equipment has not been available. One is under construction and when it is available experiments will be conducted and unquestionably the problem of a "flying moor" to the low type of mast will be simplified if not solved completely. The difficulties of a mooring approach to a low mast lead to the suggestion of a telescopic mast which may be 120 feet or so high for the mooring maneuver and thereafter collapsed to a height suitable for riding. Such a mast is a future possibility.

Towing or "walking" the airship across the landing field is a necessary step in docking the airship in its shed. The airship must be kept headed into the wind until brought to the position for

swinging her and centering her between docking preparatory to hauling into the shed. This frequently means the airship must be moved sideways. In the operation of walking across the field the full man power of a competent ground crew has been required, the airship being held by bow lines, numerous side handling lines and by men grouped around the forward and after cars. The desire to reduce man power coupled with the conviction that the bow was the only suitable place from which to tow an airship led to the conception of a mobile stub mast. One such mast is under construction but not yet completed. It is expected to be a great aid in airship handling. It will be an awkward looking structure, comprising a mast whose height can be varied from 70 to 40 feet, mounted in the center of a 60-foot triangular frame. Under each corner of this frame is a wheel of the self-laying track or caterpillar type. At first, this contrivance, weighing about seventy tons, will be towed by a tractor. A self-contained drive can be included when the practicability of the device is assured. Hauling-in winches, ballasting and fuelling facilities, and other desirable equipment are mounted on the mobile mast so that it will be in every way as complete as the high mast now is. While this auxiliary equipment is not necessary for towing across the field it is necessary to the operation of mooring to the mast. During mooring, tractors will be used to handle the yaw guys.

During the maneuver of towing across the field, the stern of the airship will be supported on a "taxy-car" provided with a castering wheel and ample shock absorbing ability.

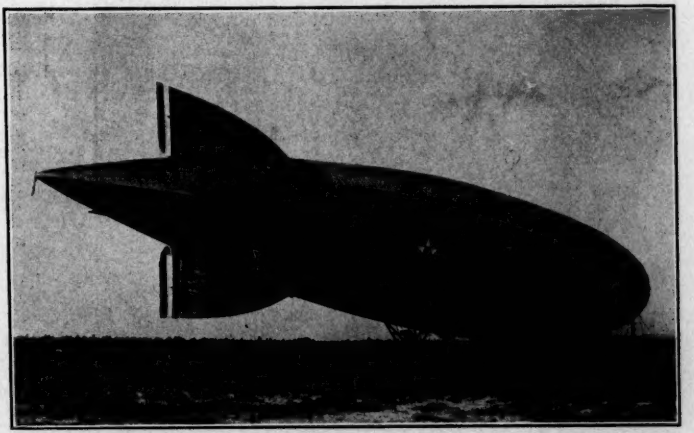
A certain number of men will always be necessary to the operation of docking the airship but their number will depend upon how successfully tractors and similar equipment can be adapted to replace them. The present belief is that carefully tended tractors carrying sensitive-controlled winches can control the necessary side handling lines almost as well as a large crew of men.

It is when it becomes necessary to haul the ship away from her normal "into the wind" position that side force is exerted on the ship. This may occur in swinging the ship or in centering her on the docking rails. The guiding principles are to distribute the force along the ship's length; to keep the windward lines taut; to keep the leeward lines just taut; and thus keep the airship under

(*Navy Photo.*)

FIGURE 7.

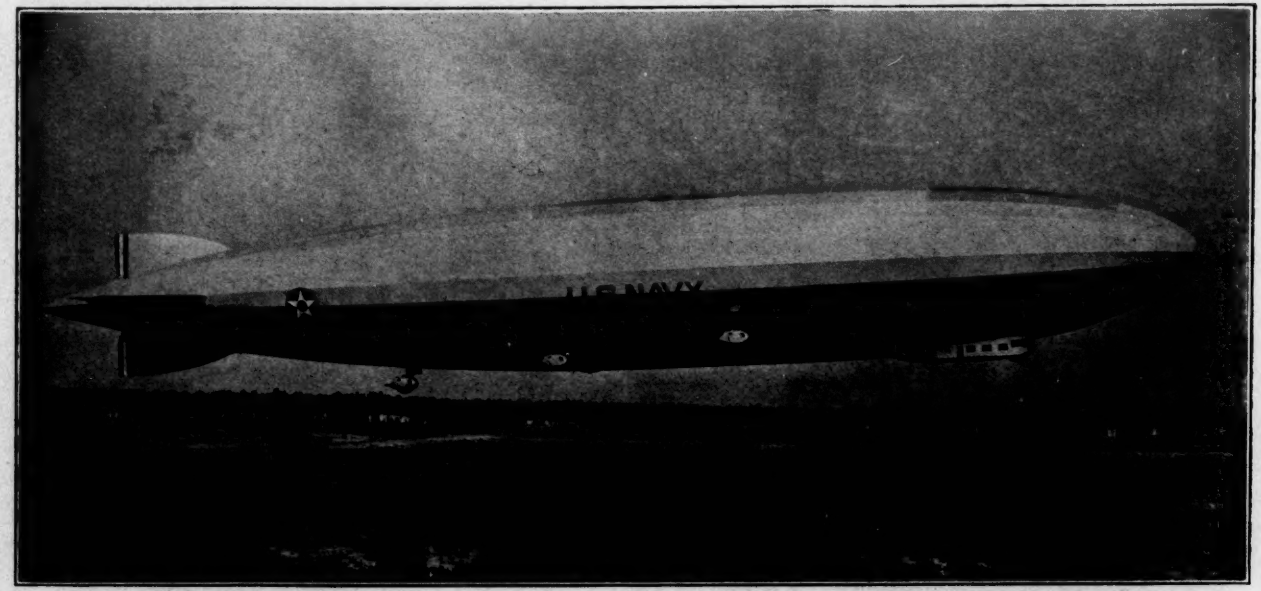
U. S. S. *Los Angeles* moored to a simple type of stub mast, erected on short notice at Panama, February, 1928. The taxy-wheel supports the aft engine car.



(*Navy Photo.*)

FIGURE 8.

One of the first occasions on which the *Los Angeles* rode to a stub mast. Reinforcements to aft engine car; taxy wheel underneath car; handling frame; and tail drags are shown in this picture. The prepared circular track and its accompanying car are later developments.



(*Navy Photo.*)

FIGURE 9.

Los Angeles casting off from the Lakehurst stub mast. The circular track, on which travels the car supporting the aft engine car, may be seen in the foreground.

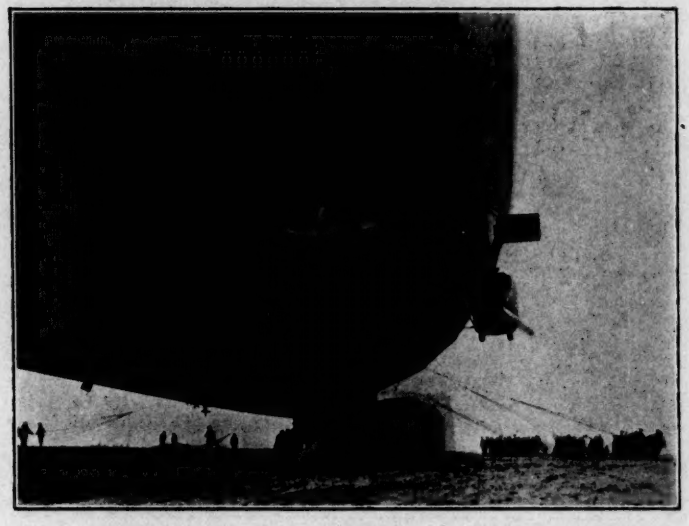


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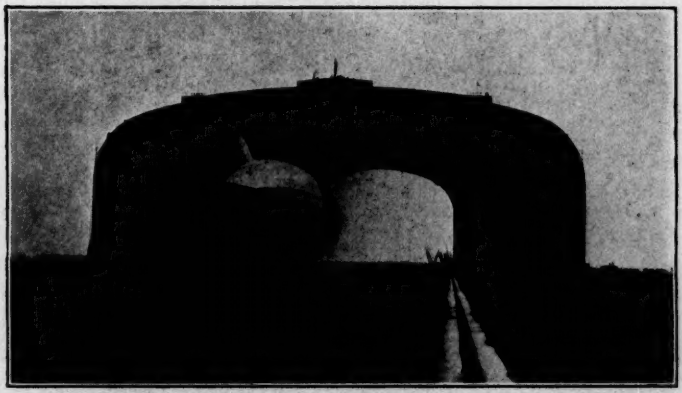
FIGURE 10.

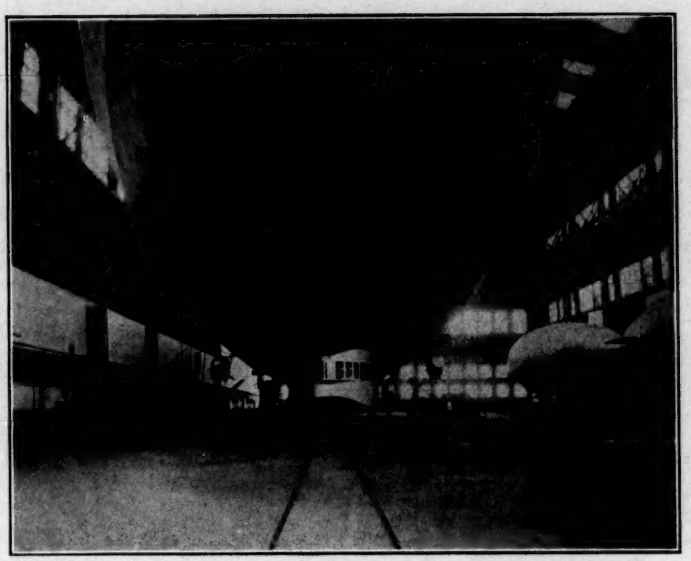
Forward car party and forward side line groups holding the *Los Angeles* against moderate side wind in walking the airship across the field. Water recovery units may be seen above the power cars.



(*Navy Photo.*)

FIGURE 11.

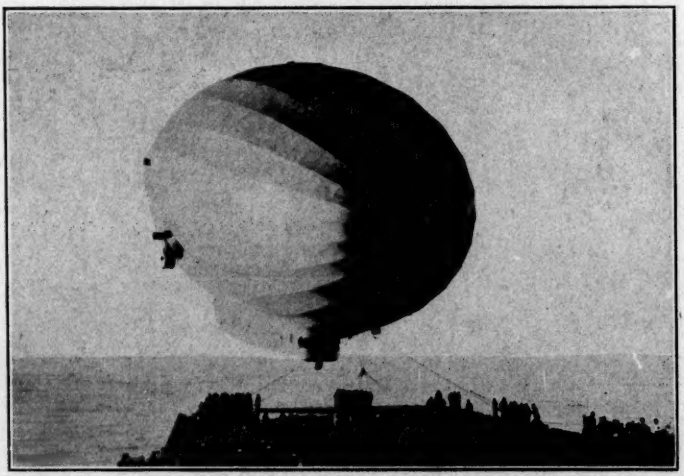
Los Angeles entering the shed at Lakehurst. The slot type docking rails, numerous side handling lines, and large ground crew are shown.



(*Navy Photo.*)

FIGURE 12.

Los Angeles docked in her shed. The special car supporting the control cabin plays a part in handling the airship into and out of the shed.



(*Navy Photo.*)

FIGURE 13.

U. S. S. *Los Angeles* landing on flying deck of U. S. S. *Saratoga.*

control at all times. Team work is required but it is believed this can be supplied by man-operated appliances rather than by a large force of men alone.

For hauling the airship into and out of a fixed shed a pair of suitably spaced docking rails are provided extending out from the shed a distance great enough to permit the airship to be hauled clear of any down-spill of air over the shed roof. The customary practice has been to fix the position of the airship between the rails by two side lines on either side leading to docking trolleys which travel over the rails. Tractive force for the ship and the trolleys is now supplied by man power and additional men are required for side steadying lines, not attached to trolleys, and for tending the forward and after cars.

The necessity for taking airships out of sheds in higher cross winds, and the necessity of preparing for larger airships of the future has led to the development of a somewhat more elaborate system of side handling lines for holding the airship between the docking rails. Several trolleys are used on each side and are separated by spacer struts. Instead of only two side lines, there are two systems of lines on either side. Each system is rove through trolleys and attachment points on the airship in such a way that loads in the several parts of each system can equalize and thus avoid concentration of load at a single point. The docking trolleys on each side, connected by their spacing struts, will be hauled along their track by a small "mule." The after car will rest on the "taxy-car." The airship itself will be towed by the mobile mooring mast (or else by a tractor pulling at the forward car).

Quick release devices are built into the side line systems and can be tripped in an emergency. The usual procedure, however, on the airship reaching the end of the rails is to swing her into the wind by slacking away on the several side line systems as required to permit the airship gradually and easily to take a position into the wind.

For docking the airship in a shed there is the choice of supporting her from above by slings; from below by shores; by a combination of slings and shores; or by keeping the airship "light" and holding her down by lines forward and aft. This latter method

has been developed at Lakehurst and gives good service. Scales are placed in the system and by taking readings the equilibrium condition of the airship is accurately determined. A watch is always on duty to correct abnormal changes by varying the ballast or other weights on board. Side handling lines, and fore and aft surge tackles, slightly slack, are left in place to serve as preventers.

The condition of riding to a mooring mast has already been discussed somewhat. It remains to point out the advantages of a stub mast as a point to ride to. The advantage follows from the hypothesis that gusts, especially vertical gusts, are fewer and less severe near the ground. Further by keeping the airship properly trimmed, and slightly heavy, and allowing her stern to rest on a traveling support of some sort, the tediousness of keeping constant watch is very much reduced. If necessary, or considered desirable, the carriage which supports the after portion of the airship can be fitted with hold-down devices. This led to the adoption of a circular standard gauge railroad track concentric to the stub mast. An alternative is a smooth circular roadway, possibly concrete, on which there travels a fairly heavy car. The car can be ballasted to resist any possible rising tendency of the airship's stern. This would be the cheaper installation. Experience will show which type — the track with light car and hold down device, or the smooth roadway with heavy car — is the better.

Such is the stub mast system stripped to its essentials. Additional equipment, such as stern weighing devices, will be found desirable. From experience to date the airship answers very easily to sudden wind shifts and gusts. If it be found that the resistance of the stern carriage is too great for the airship to drag around, some automatically operated power-drive can be incorporated into the carriage.

Taking off from the field is not difficult but requires man power to hold the airship prior to the take off. Casting off from a high mast is comparatively simple. Casting off from a stub mast is more difficult, on account of the danger of the tail striking the ground before the airship is clear of the mast. However, the maneuver, while a ticklish one, can be made and is not so difficult as the maneuver of mooring to a stub mast.

When all the equipment above sketched is available and perfected it is expected to be able to carry out the following: Attach

mobile mast, taxy car, etc., to the airship while docked in a shed; tow out of shed in cross winds up to say fifteen miles per hour; swing ship into wind; tow across field and position mast in center of prepared track; attach stern carriage; allow airship to ride indefinitely, moored and supported in this fashion. Or, with airship moored, to cast off the stern carriage, attach the taxy wheel and tow her by means of the mobile mast into the shed by a reverse process to that described above. Or, with stub mast in position at center of circular track, to bring airship in to a "flying moor," attach stern carriage and ride indefinitely.

Landing the airship *Los Angeles* on the deck of the U. S. S. *Saratoga* in February, 1928, was a nice piece of airship and vessel handling. It was successfully accomplished without the aid of any special equipment other than the "bumper bag" and handling lines normally carried by the airship. From the experience gained on this occasion comparatively simple equipment can be designed and provided and will make future landings on decks of vessels very much easier. There are some airship pilots who hold the opinion that a temporary landing of this sort for re-fuelling is preferable to mooring to a floating mast for the same purpose. Other possible ways of re-fuelling at sea or from a tender, and means for towing airships at sea are problems to be attacked and solved as the development continues.

Predictions are risky, but the hope is that with suitable equipment any of these routine mooring and docking evolutions for a large airship can be performed with a ground force of one hundred and fifty men and some with even a much smaller number. If this hope can be realized, and we believe it can, the time, effort and money will be well spent and much will have been done to increase the utility of large airships. The non-availability of satisfactory handling equipment is today a big handicap to airships and one that must be overcome.

BANQUET OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS,
THE NEW WILLARD, WASHINGTON, D. C.
JANUARY 18, 1929.

PRESIDING: REAR ADMIRAL C. W. DYSON, U. S. N. (RETIRED).
TOASTMASTER: REAR ADMIRAL R. H. LEIGH, U. S. N.

REAR ADMIRAL DYSON: *Mr. Secretary, Members of Congress, Military and Naval Attachés, and our numerous friends in civil life engaged in pursuits allied with the Navy:* A speech is something that I cannot make and I am not going to try to make one, but I am going to tell you a little history of engineering in the Navy. The junior ones among you may not realize that engineering is comparatively young in the Navy. At the outbreak of the Civil War naval engineering was in its infancy. In fact it was such an infant that there was a question among the older officers of the service as to whether the steamship was a desirable naval vessel, whether the sailing vessel was not better. That being the case, in all ships of the Navy that had steam it was a mere adjunct; the main propelling power was sail except in the Monitors. The engines were very small and so remained until the building of the new Navy, begun in 1883. In that period the *Trenton* was the prize ship of the Navy. She had about 3000 horsepower and could make 14 knots — so they said. The other ships were sloops that could do about 8 or 9 knots with about 800 horsepower. Under these circumstances the ambition of the officers became deadened and interest in the engineering profession was perfunctory. But there were some among the officers who still held up the torch of engineering during this period of neglect, and Congress helped by instituting a course at the Naval Academy for cadet engineers. For the first few years this course had a length of two years. In 1874 the course was extended to four years. These classes were retained until 1882 when Congress amalgamated the

cadet engineers with the cadet midshipmen and changed the title to Naval Cadet. During this period these classes were admitted to the Naval Academy by competitive examination. Any young fellow with a high school education, putting in his application, with report as to good character and general health, was permitted to come to Annapolis and take the examination. A total of 25 were admitted each year. The year that I took my entrance examination there were something like 300 candidates of which only 25 were admitted.

These men were among the most brilliant men that this Navy has ever produced, in my opinion — Admirals Taylor, Stahl, Baxter, Bowles and Gatewood; cadet engineers in the straight line of the Navy — Admirals Strauss and Halstead; among the engineers, Griffin, Bryan, McElroy, Burd, Kaemmerling, Norton; and of the two-year classes, Canaga, Bailey and Mattice. Those who went out in civil life later on — McFarland now with the Babcock and Wilcox Company; Hollis of Harvard University, later President of Worcester Polytechnic Institute; Spangler of the University of Pennsylvania; Cooley of the University of Michigan, and Creighton of Purdue. Upon the shoulders of those who remained in the Service fell the burden of the rebuilding of the Navy and the men at the colleges were practically the fathers of engineering education in the universities of the United States.

In 1883, when the first real steam ships, *Chicago, Atlanta, Boston* and *Dolphin,* were contracted for, in order to make sure that no mistake would be made in the design, a Consulting Board was constituted consisting of three civilian engineers and two officers of the Navy. I think the result of their work was, to say the least, fantastic. The *Chicago,* which was the most important ship, was full rigged, with vertical, inverted, walking-beam engines. There was nothing particular of interest in the *Boston* nor *Atlanta.* The *Dolphin* made one advance, the first example we had of a fighting ship with vertical engines. Heretofore all the engines had been horizontal except those in the monitors. After the white squadron was constructed the Secretary of the Navy, Mr. Whitney, had so little confidence in the engineers and naval constructors in the Navy, that he went abroad to buy plans, buying plans for two or three cruisers. At the same time we made our own here in com-

petition against these cruisers, and we succeeded in equaling, if not in bettering, many of them.

In 1888 the engineer officers on duty around Washington, realizing that the text-books were very poor, and that there were very few, if any, marine engineering journals published in this country, got together and formed this Society with the publication of a JOURNAL. From that time on we have published the JOURNAL quarterly, giving all engineering data that was of any value whatsoever. This JOURNAL I can speak of from experience. If you cannot find anything in any other Journal you can go to our JOURNAL and get it.

After 1889 the character of our service improved until the Spanish War. The Spanish War, unlike the Civil War, lasted only a very few months. Our losses were very small, and our victories were such as to lift the Navy to the crest of popularity throughout the country. From that time on until the outbreak of the World War engineering in the Navy progressed very rapidly. During that period the turbine appeared in the field, the Diesel engine, the mechanical reduction gear, and the problem of electric propulsion. The Navy adopted every one of these as it came along and in only one case did we have a failure, and that was in the case of the *Maumee* fitted with Diesel engines, in which the mistake was made of making too big a jump in power. When the World War came our ships went to the front, and not one single fighting ship was withdrawn from the first line during the war for other than routine overhaul.

From 1883 to 1928 the power jumped from 3000 horsepower of the *Trenton* and 12 to 14 knots speed to 212,300 horsepower on the *Saratoga* and 34.64 knots speed. A middle step was taken at 90,000 horsepower on the light cruisers, the highest power up to that time having been 30,000 to 40,000 on our battleships.

Following the World War came along the Limitation of Armament Treaty. I don't care to talk about that. It caused us to lose six of the very finest battleships that had ever been designed and four of the finest battle cruisers, saving only two out of the six by converting them into airplane carriers. Equal in importance is the fact that by the limitation of armaments and the cessation of building ships the designing forces at the shipyards became scat-

tered. The men who had worked with us for years were put on the shelf, and the country is today without the skilled hands it had before the limitation of armaments. If we build no more ships we will be back where we were in 1883 when there was no one in the country competent to build ships. No man can remain of any value in his art unless he practices the art. When I read in the papers some of the reasons why we should not build ships I come to the conclusion that zoologists haven't told us everything. God has made some asses that haven't long ears.

The toastmaster this evening was to have been Admiral Robison, Superintendent of the Naval Academy. Unfortunately he is ill, but we have been very successful in drafting an equally distinguished officer who has been closely associated with engineering, having been Assistant Chief of the Bureau of Engineering for four years, having been commanding officers of one of the first of our electric drive battleships, and now being the Chief of the Bureau of Navigation. I introduce to you Rear Admiral Leigh, U. S. Navy.

TOASTMASTER: *Mr. Secretary and members of the Society:* I have looked forward with great pleasure to this evening for some time, and I have just had one of the greatest compliments paid me that I think I ever had in my life, when I was placed on an equality with the officer who was to speak to you tonight as toastmaster, Admiral S. S. Robison, Superintendent of the Naval Academy. I sincerely wish that I could come up to that high standard, but anyway you see I am here and I am going to do what I can as toastmaster.

You have heard a great deal of the history of this Society from time to time and so have I, but there are some details that have never been told which I think are quite interesting. During the past week or ten days I have been almost in daily attendance before the House Naval Appropriations Committee, and every time I mentioned a new subject somebody would speak up and say—"well what does that cost?" Now since my mind is running on the question of costs I wondered what this Society cost in the beginning. I was reading the minutes of the first meeting of the Society, and I found that there were gathered together fifteen engineer officers of the Navy, and they decided among themselves,

in order to make this Society a going concern, full of ginger and vigor, something with life in it and something good for the Navy, that they would all make a subscription, and on that evening each one of those gentlemen subscribed to the Society the magnificent sum of twenty-five cents, so that the Society started with $3.75 in the treasury. The gentleman who was treasurer at that meeting is here tonight, one of our honored members — Admiral Griffin. He was relieved in a short time by another member who is here tonight, one of our distinguished members, one of our good friends who did not stay in the Navy, but who has always been a Navy booster, and who has helped us tremendously in civil life, and that is our good friend Mr. Walter McFarland. When the time came for Admiral Griffin to go to sea, I noticed in the history of the Society it was stated that he was relieved by Walter McFarland who served "without compensation or other emoluments."

Gentlemen, the history of this Society covers a span of 41 years in which there has been the greatest scientific development in the history of the world, and those officers who got together in those days and formed this Society started a JOURNAL to give facts and data and preserve them. We all know of its wonderful success. They put their hearts as well into this work and we are the ones to benefit, and those who come after us will still benefit, and I feel that our thanks are due to those officers.

In the same year that this Society was founded there was graduated from the Naval Academy a young man who first distinguished himself in his profession and on the bench in civil life, and who is particularly well equipped to speak to us tonight on the subject of the Navy, and it is a genuine pleasure to me, gentlemen, to introduced to you our Secretary, the Honorable Curtis D. Wilbur.

SECRETARY WILBUR: *Admiral Dyson, Mr. Toastmaster:* I know that we were all glad to hear Admiral Dyson, but I wish that he had not been so modest and had told you that the *Lexington* and the *Saratoga* were equipped with Dyson propellers; the *Leviathan* as well. Admiral Dyson has been an inspiration to me although he perhaps doesn't know it, because he has illustrated so forcibly the fact that a man who sticks to a problem will be a very great asset not only to the Navy but also to the nation, for the saving

in fuel consumption due to some of the suggestions of the Admiral will be a distinct asset in the development of our merchant marine.

In talking to a group of engineers I am reminded of an incident which I think is authentic. A man was offered an appointment as a judge in the British West Indies. He had never studied law, and felt that he was not qualified to hold a judicial position without having studied law, and in his uncertainty he went to the Lord Chief Justice of England, Lord Mansfield, and asked his advice, and he received this advice: "Accept the appointment, use your common sense and your best judgment and decide the cases in accordance with your judgment as a man of good sense, but never under any circumstances write an opinion." He accepted the advice and for a number of years was extraordinarily successful on the bench, so that he came to have a reputation as a great judge. Somewhat stimulated by this high public esteem, he decided in a comparatively simple case that he would violate the rule that was laid down for his judicial conduct, and he wrote an opinion giving the reasons for the decision which he rendered. Although the decision was correct, the reasons were so bad that the lawyers sought to impeach the judge for his ignorance.

It seems to me, therefore, that it behooves me, in addressing a group of engineers, to avoid going too much into detail concerning the engineering profession. I sometimes wonder, as I look at engineering problems in the Department of the Navy and in civil life, if we have not, in our multiplicity of new engineering problems and scientific problems, forgotten some of the advances that were made in the past, and some of the difficulties confronted and overcome. Perhaps we have disregarded the importance of the original efforts which led to the invention of the steam engine. I have been very much impressed during the last two or three years in visiting the hull of the *Old Ironsides* at Boston. Not a very inspiring sight unless one goes into details in the examination of the hull and tries to take in the magnificent manner in which this ship was constructed. Viewing the ribs of the *Old Ironsides*, her timbers revealed by removal of planking, considering the original purpose and plan of the architect as presented to George Washington through his Secretary of War, Henry Knox, we realize that the success of the *Old Ironsides* in battle was not an accident, and

though much was justly credited to the captain and the crew, a great deal of the credit should have been given to the architect who designed and built this wonderful ship. They had their problems in those days.

I wonder sometimes, in the consideration of the problems of preparedness upon which we all agree, if the public gets a just conception of what constitutes preparedness. There seems to be a feeling among the less informed that preparedness means the acquisition of ships — an engineering question; among the better informed, that it includes the more important function of training the personnel — officers and men. But as important as these two are, the training of men and the acquisition of material, there seems to be something more fundamental today in our problem of defense than either of these two requisites, namely, the necessity of scientific development, and the appropriation of scientific knowledge to the problem of national defense, and the effort to do this is being made, I think intelligently by the Navy of the United States. This is the development to which Admiral Dyson referred in the account of his forty years of experience. The difference between the newer ships and older ships makes us realize that in modern battle it will be the nation which has kept track of modern development and has participated in that development and has made scientific advancement, that will have the advantage in a new war, and with that advantage achieve success.

This is not the time nor the place, nor would it be at all desirable to undertake to indicate any of the lines of development now underway in the Navy, or the problems that are being solved in the Navy, but it may be worth while to remind ourselves that, after all, the Navy is a great laboratory, in which on a magnificent scale we are testing out scientific principles, developing them first in the laboratory, then in the gun factory and the shipbuilding plant, and later in the actual maneuvers of the ships. Every target practice is for the training of personnel in the operation of the ship and its instrumentalities but in the larger sense it is the development by experimentation of the principles relating to national defense. So that I may say tonight to the members of Congress here that the money expended for ammunition, projectiles and powder is not alone utilized for the training of the men and officers, but is

also utilized for the development of the science of gunnery and of naval defense, and that those developments will be utilized in new ships and new guns, and will be available in the case of war. I believe that in the next war, whenever it may come, and God grant that it may be a long time away, the battle will be determined by principles and developments not yet undertaken. I do not necessarily mean radical departures from the type of instrumentalities now used and which have been used in the past, but it will be only by the conscientious and consistent and long continued development of these instrumentalities that the nation will find itself fit and prepared in the case of war. The airplane gives us a very excellent illustration. The airplane today represents to us a new development, and we believe it is at the threshold of larger developments. We realize, in the production and manufacture of these planes, that it is a principle laid down by the Navy and the Army as well that the life of a plane is only three years, so, unless we visualize a war within a short period, every dollar expended in the preparation of a plane, in its manufacture and in its utilization, is spent only for the purpose of developing a plane which is yet to come.

May I express in closing my pleasure at being with you here tonight participating in this period of good fellowship, listening to the men who are on your program, the eminent engineers who have already addressed you and the others who are to follow. It is a great pleasure and I appreciate it; and may I, not only in my own behalf but I trust on behalf of the others here, engineer officers of the Navy, express our great appreciation to the members of the Naval Committee of the House and of the Naval Appropriations Subcommittee of the House and to the members of the Senate, who have taken the trouble to come here and join with us tonight. If this were the time and place I should like to speak to you somewhat on the development of the Navy and its relation to the people of the United States. I believe that it is necessary, not for the passage of the bill now pending before Congress, but rather for the orderly and continuous development of the Navy of the United States, that every one interested in the Navy, and understanding the underlying principles and the difficulties attendant upon such defense, should, when opportunity

offers, bring the facts and the principles to the attention of the people of the United States, for after all Congress legislates for and on behalf of the people of the United States, and the impulse for an adequate Navy must come from the people of the United States. That you will, as part of your work as engineers, familiar with the problems of marine engineering, take on this added duty, I feel sure.

I thank you for your courtesy, and again express my appreciation for the opportunity of addressing you.

TOASTMASTER: The next speaker, gentlemen, was born in Brooklyn, New York. He was a boy in New Jersy, a cowboy in Nebraska, a young business man and real estate industrialist in New York, a lawyer in the State of New York, a mining engineer, an agriculturist, a district attorney, a State Senator and a Governor in Nevada, and a United States Senator in Washington. Best of all he is a real sailor at sea and one of the best of our Navy friends, an understandable and understanding Senator. He is going to give us a brief talk on the Navy. It is my pleasure to introduce to you the Honorable Tasker L. Oddie, Senator from Nevada.

SENATOR ODDIE: *Mr. Secretary and friends:* I feel very much embarrassed at the introduction Admiral Leigh has given me. I am reminded of an incident that happened in Nevada some years ago in a mining camp. I have had some experience in mining camps. This was during a mining boom. Somebody in the east had bought some mining stock that was placed on the market, and he wrote a friend of mine for particulars. In his questionnaire were these questions: How much does the general manager of the company get? How much does the superintendent get? How much do the shop forces get? How much do the engineers get? How much the blacksmith, and so on all down the line. The answer came back — he gets four dollars a day.

Now my friends, I should have said something to my friends in the other side of the Capitol, those hard working members of Congress who also have the interests of the Navy at heart. I have had the pleasure of being with them a great deal, and I want to compliment the Navy on having such men to deal with. It is not always possible for the members of the Appropriations Committee in the Senate or the House to give the Navy what it needs. Many

of us would like to give the Navy more. But we are hemmed in by certain rules and regulations. There is just so much money in the Treasury, so we cannot always do what we would like to do. I am reminded of the story of a colored preacher who wanted a better job, so he applied for the position as minister in a church in a large town. He was called to preach a sermon on the following Sunday, and the congregation was to decide whether they would accept him or not. He preached a very eloquent sermon and gave a very fervent prayer. After church the members got together to decide whether they would have him or not. One of them said: "I don't think I want to have him here, he isn't a practical man. He asked God for a lot of things he didn't have." I am reminded of that story in our Appropriations Committee.

Now, my friends, I am not going to give you a technical discussion, because you are technical men, and you understand more about these matters than I do. I am a civilian trying my best to learn the problems of the Navy, and trying the best I can to give the Navy what it should have. We have something to contend with in this country, I might classify it — an un-American pacifist. I don't refer to those men and women who honestly believe that we should not have a Navy and an Army, but I refer to those who are mischievous in their statements, and who do not talk as if they were good Americans. We hear a great deal today from these people. Their organization is preaching their doctrine. But I wish they would understand history a little better, and realize that when a country has allowed its Navy to depreciate, that country has generally gone to decay. We want to keep our country healthy and prosperous. To do it we must have a correspondingly healthy and virile and strong Navy. We hear arguments and statements that are not even worth while to mention. For instance, men will argue with us every day that an airplane will go out and drop a bomb on any battleship or cruiser, and sink it. These men have never been to sea. Unfortunately they do not know the difference between a battleship and a destroyer and they class them all the same. They think there is no such thing as low visibility at sea, and that there is always clear weather; that a battleship or a fleet could be five hundred miles at sea or a thousand miles perhaps, and that any plane could go immediately to

any of those ships, drop a bomb on it and sink it and return safely to shore. Now I do not have to tell you men how absurd that statement is. And yet the idea that is being carried through this country by pacifists and the unthinking on these problems is doing a great harm. It is a harm to a principal branch of our service. It is assuming that our air forces are men of small intelligence, that they would be willing to do away with battleships and cruisers and a balanced fleet. They are insulting the intelligence of these men, and I think, the people of the country. These arguments are intended to take away the support from the air forces, so that the air forces would not, in case of emergency, have the support of a balanced fleet.

I do not have to explain to you in regard to our cruiser bill that we are engaged on and hope to get through, that it is not because we expect to be in war, but because in having an adequate force we will do more to prevent war than in any other way. The impression has not gone over the country as it should, that some of these proposed cruisers will take the place of old obsolete ships that are practically worthless today; that they are replacements to a large extent. There are many of our friends in this country who do not understand these things, and who do not realize that to have a successful defense we should have not only a strong Navy, but we should have a strong merchant marine, and adequate and well placed bases. Unfortunately, we are not as strong in these branches as we should be, and we hope the American people will assert themselves, and let Congress understand in no unmistakable terms that the American people demand these things that can and should be had in the interest of national safety and defense and of the national prosperity. We hope to get this bill through. We fear a filibuster against it. We can see signs of it now, and we know why this filibuster may start. But in the mean time we hope that the right information will come to those who may propose such a thing and that they will be deterred from doing this. I want to see this bill go through quickly. The House has done its duty and sent the bill over to us in the Senate. We lack certain rules which would enable us to put things through a little quicker than those people encounter, but I hope that the Senate will acquit

itself as the House has and pass this bill in the interest of the prosperity of the country and of national defense.

I appreciate very much the opportunity that has been given me to attend here tonight, and I am looking forward to some very interesting discussions. I wish you all well and every good thing that can come to the American personnel and officers, and I know there is no better body of men on earth. I take pride in the Navy, and I feel myself honored to have been put in a position where I can meet officers of the Navy, and I congratulate our country on having such a body of men. It was stated on the floor of the Senate the other day that this country never need fear any dangers from warriors from other countries, that the great danger that might come to us would be from traitors from within. I thank you.

TOASTMASTER: I thank you very much for your excellent address.

We have another one with us here tonight born in Brooklyn. We all know him too well for me to go into detail, how he rose very quickly to become Engineer-in-Chief, and we know of his subsequent work. It would take your valuable time if I were to go over these things tonight. I ran across one of his shipmates the other day, and I wanted to find out whether this young man, when he was a young man, gave promise of becoming so prominent in engineering as he has. He said: "Well, I don't know, but I can say this: on our ship we had an old chief machinist named Fitzgerald. Everybody loved him not only for his fine qualities, but because of his proficieny as a machinst. This machinist was working one day on a piece of machinery, doing a very difficult job. As he was working away, with much profanity, this gentleman came along and said: 'Fitz, don't you thing you would get through quicker if you stopped swearing?' 'Don't I think I'd get through quicker? Why, sir, if I could swear like you I'd have finished this job an hour ago.'"

Our next subject is one in which we are all intensely interested, the Merchant Marine, and it gives me pleasure to introduce to you Rear Admiral Hutch I. Cone, U. S. Navy.

REAR ADMIRAL CONE: *Mr. Toastmaster, Mr. Secretary, honored guests, and fellow members of this Society:* The Merchant

Marine has had its ups and downs all right. By drafting me to represent it here tonight in this distinguished assembly, and to compete with the finished orators who have come before me, is hard luck for the merchant marine again.

When we were a small country, inhabiting only the eastern fringe of our land, we were leaders in the merchant marine. We did not need foreign markets, and as long as that condition obtained we kept in the lead in the merchant marine. Then came a time when we were busy developing the country, and we forgot all about the merchant marine. We let others carry our sea-borne commerce with the result that throughout the lifetime of all of us here we have had no merchant marine to speak of. The time has arrived when we have got to look for foreign markets. We have got to depend on the export of our surplus manufactured products, and we are waking up to the fact that we have got to have a merchant marine, and those of us who are interested and charged with this work believe that this country is going in strong for a merchant marine. The best evidence that we have of this is the passage by the last Congress of the Jones-White bill which was designed to assist merchant ships to meet international competition on the sea. I will take a minute to explain to you my conception of what this bill means. I know that most of you are familiar with it, but I see many here tonight that are going to have much to do with the design and construction of ships that we hope will follow as the result of this assistance by Congress. It is a waste of time for me to explain to you gentlemen — you are all familiar with it — the differential that obtains against our ships in their operation on the sea. I will mention, however, that the most serious of these handicaps that we have to contend with in meeting foreign competition is, strange to say, not in the operation of the ship, but in meeting the capital charges. I mean by that, that when our shipowner pays the price necessary to have a ship constructed in this country, the interest charges, the insurance charges, and the depreciation of the more expensive ship handicaps him seriously in the competition with the foreigner. The Jones-White bill contains a feature designed to remove some, if not all, of this handicap, and that is the construction loan feature of this bill by which a shipowner may borrow from the Government three-

fourths of the cost of construction of the ship and have the capital amortization spread over 20 years with an interest rate that figures out now at about 3⅛ per cent, provided the ship is engaged in foreign commerce. We hope that this will remove considerable of our handicap along this line.

The other and more generous help designed to remove the remainder of this handicap, and also make up some of the difference in the salaries of the personnel, is the compensation by the Post Office Department for the carrying of mail on certain mail routes. This feature of the bill we believe will be most important in putting on the sea under the American flag, high speed and high class passenger liners, which of course to the Navy is most important. I personally am busy with this aid to the merchant marine, and we have before us now plans and specifications and requests for Government loans which indicate clearly that we should have under construction at least fifteen or twenty of these ships in the immediate future.

Now you gentlemen, I am not going to say you naval engineers, but will say we naval engineers, have more to do with the design of a merchant ship than is the case in most countries, for the simple reason that we have had no merchant marine to develop the designer and builder of that class of ship. Hence the designers and constructors of our Naval craft have lead the way, and they are the men on whom we must depend in some part for the construction of the merchant marine. Such ships as the *Saratoga* and the *Lexington*, of which we are all very proud, have certainly blazed the way in the matter of speed in the merchant marine. We believe, in fact we know, that we are on the eve of increasing the speed of passenger travel at sea in the immediate future. There are a number of liners laid down that, while they do not equal the speed of the *Saratoga*, approach such speed, and we have in sight — we hope to sail under the American flag — ships of the same character.

There is one thing that I have noticed in my activities since being connected with the merchant marine, and that is that practically every one that starts out to argue for a merchant marine uses as his first argument the need of a merchant marine for national defense. Certainly you naval engineers need a merchant marine

to practice your art in order to design that much better for the Navy, and certainly the merchant marine is practically dependent on the men of your type to develop the high class ships that we will need. Only recently the Shipping Board has gone to this Congress and asked for a sum of money — and we have every reason to believe that we will be granted a generous sum — to be expended in engineering developments. The foreign merchant ship has enjoyed a great deal at the hands of the owner in the way of money expended in research and scientific development, because the foreign shipowner could afford to pay the bills. In our country unfortunately the merchant marine has not been sufficiently prosperous to supply the money needed for engineering development. Engineering development in the merchant marine is more necessary at this time than in the Navy for the simple reason that due to lack of business in the past we are behind the times. With this money we hope to utilize the brains of men in this room to help us to improve and advance engineering in all of its branches for the merchant marine, and I say engineering in all of its branches advisedly because, strange to say, marine engineering is not the only engineering that is involved in the operation of merchant ships. A large part of our freight money is absorbed in the terminals where engineering has been woefully lacking.

I had intended to finish my speech by referring to a lot of distinguished engineers, but Admiral Dyson has stolen my thunder, so I will close by thanking you gentlemen for your patience in listening to me and wish you good night.

TOASTMASTER: The name of the gentleman next on the program is Henry G. Smith. He is not able to be with us tonight on account of sickness, but we are fortunate in getting another who has consented to come in his place. The gentleman who will speak to us is an eminent engineer. As a young man in England he attended one of England's finest engineering institutions, and he has had a varied experience in other countries. We have known him here with us at the Bath Iron Works with our good friend Mr. Charlie Wetherbee, who is also with us here tonight. He is now with the Bethlehem Shipbuilding Company in the capacity of chief engineer of that company, and in bringing the aircraft carrier *Lexington* to completion he was directly responsible in a great

measure for the excellent results which have been obtained. He will speak to us on the subject of Shipbuilding. It is a pleasure for me to introduce to you Mr. J. B. Burkhardt.

MR. BURKHARDT: *Mr. Toastmaster, Mr. Secretary, honored guests and Gentlemen:* Mr. Smith asked me to convey to you his deepest regrets at not being present tonight. On Wednesday he underwent a minor operation, and although his general health is not bad by any means, his doctor did not want him to leave New York. In any case if he had, he would not have been able to speak to you. I am sorry that he is not able to deliver this talk because Mr. Smith in the last two or three years has been engaged on work of such general importance to shipbuilding that he is particularly fitted to give you a picture of the indutsry as it is today, and I am not able to fill his shoes in that respect.

In speaking to you tonight I am speaking to shipbuilders. The Navy is now a shipbuilder, and if the present plan goes through, it may be one of the largest shipbuilders not only in the country, but perhaps in the world. Historically the industry is among the first. The art of shipbuilding has always been and always will be of the greatest importance to every nation. On 1 January 1916, 26 shipbuilding yards were in operation in this country, and now there are 12. I said 1 January 1916. That was not during the war boom. It was 14 months before we went into the war. Of these 12 yards in operation today it is hard to tell at what capacity they are operating, but we do know that the three largest shipbuilding companies employ at this time collectively about 7,000 men. Any one of them could easily employ that number working at normal capacity. Probably the industry as a whole at the present time all over the country is operating at about 30 per cent capacity.

The shipbuilding industry is very grateful for all that has been done in its behalf. They are particularly appreciative of the Jones-White Bill. There are already three vessels under contract that would probably not have been built without the assistance provided for in that bill.

We hear a great deal about high cost of building. I was talking the other day to a man in Boston who operates a number of 8000-ton colliers, that were built over 20 years ago, and cost about $400,000 apiece at that time. These boats are getting old, and he

realizes that before very long replacement will be required, and he knows from inquiries he has made from the shipbuilders that new vessels today will cost somewhere around $800,000 each. It is hard for him to get used to the fact that costs have doubled in that period, and he hopes that we can give him a new vessel so superior to his old ones in operating cost as to offset the increased capital charges. Of course this is impossible, but I think the Jones-White Bill is going to help that very considerably by enabling the owner to finance the new vessels more cheaply.

I do not know whether I should venture on Navy Yard versus private shipbuilding. It is a very delicate subject for me, but I can say that no shipbuilder objects to some Navy Yard building in order to round out employment in the Navy Yard, check up on costs, or for any other purpose the Navy may consider desirable. But to split the work up between private and Navy Yards on a fifty-fifty basis, or worse at this time when the shipyards are fighting for existence, working at 30 per cent capacity, is naturally objected to by all in the shipbuilding industry. All of you must know without my saying it that in case a national emergency should arise, work on the Navy Yard cruisers would be stopped instantly. The Navy Yards would be working at 100 per cent capacity on maintenance of the fleet, and the burden would at once fall upon the shipbuilders to carry on construction. Now we can not be ready in emergencies unless something is done to help us in peace times. The yards must be maintained if they are considered to be necessary in an emergency. In other words, we can not expect preparedness unless we can maintain yards in peace time.

Any break in the continuity of Naval construction is detrimental. The present program of building brings out the effect of a lapse. We are having difficulties that can be traced to the fact that the subcontractors, who supply a great deal of machinery equipment for these vessels, have not been doing Navy work for several years and are therefore not familiar with the specifications and exacting requirements of Navy work. I do not know whether you know, perhaps you do not, that 78 per cent of the money a shipbuilder receives from the Navy in payment for a vessel goes into labor directly or indirectly, about one-half of it in

the Shipyard itself and the other half divided among a very large number of subcontractors. Now with practically no Navy work in the last four or five years, there has been a cessation throughout the subsidiary industries. The Navy, too, has had to build up its inspection force, and we can see quite a number of cases where these difficulties we are having are traceable very much to the discontinuity of Naval construction.

Fore River at the present time is working at the lowest capacity in many years, and it is very difficult to keep the young people in the industry. It is hard in the first place to get them in, and it is very hard to keep them in when they see so little in the future. It is quite embarrassing to have a young man come into your office and ask you what you think of the future of the business. He wants to know if he is in the right business and it is a very difficult question to answer.

Engineering in shipbuilding at the present time presents many problems. There are so many different kinds of propelling machinery, and the shipbuilders are naturally expected to meet the requirements of the new ideas in merchant marine development. I do not think the shipbuilders will be found wanting provided a reasonable amount of actual construction is not delayed too long. We still have faith that it is coming and that we have reached the time when things are going to improve.

In the merchant marine one of the most striking things that we have today from an engineering standpoint is the great attention that is paid to the different types of propelling machinery. The owners have heard so much in the last two or three years about these various things — electric drive, geared turbine, reciprocating engines, Diesel engines, etc., that the inquiries from our customers very rarely ask that the ship have a certain kind of machinery, but request at least two alternatives, sometimes as many as four, and we spend a lot of time going into these proposals, although we know before we begin that at least one of them or possibly two, are going to be impossible, and it is really a pity to go to the trouble to look into it.

In order to give our customers an idea of the effect of some of these modern improvements on fuel consumption, I drew up a list arranged in order of their economic importance, taking into

account first cost, and it may be of interest to the members here tonight. Roughly speaking, the reductions in fuel consumption that we can expect are:

Hull, including propellers and fairing of the stern	8 per cent
Superheat	10 per cent
Air Heaters	4 per cent
Boiler design	5 per cent
Steam pressure	3 per cent
Turbine design	3 per cent
Auxiliaries	5 per cent

All are as compared with current practice of a few years ago. When I read that list to some of the owners they were very much surprised because they had the idea that steam pressure alone would accomplish as much as all of them together. The effective total of all these, assuming that all are adopted, is about 32 per cent, and that will not take care of the very big difference in cost, of which I spoke before. The figures are, of necessity, approximate only and apply to the usual merchant job of 2000-4000 S.H.P. per shaft.

The Navy interest is entirely different due to much higher powers and the effect of weight. The Treaty Limitation of tonnage has created certain engineering conditions that make weight almost a paramount consideration in the Navy today. It is a pity that it is so because I think it will hold back development in the Navy along the lines of fuel economy. I think that the tendency will be from now on for the fuel economy in merchant work to move forward and pass Navy work in that respect, and this may be very important in the future.

Many things besides type of main propelling affect fuel economy. To illustrate this I would like to bring out the case of the last Coast Guard Cutters. We have just completed five Coast Guard Cutters, and if you remember, about six years ago there were four built on the West Coast. When I was at the Bath Iron Works one of these vessels was sent there to be fitted up for an elaborate series of tests for measuring oil, water, and almost everything, so that we got some very good data from this first Coast

Guard Cutter. Now we have just completed five new Cutters at Fore River and put one of them through a series of trials quite equal to those we undertake for the Navy, and we got the astounding result that the second Cutters are very much more economical than the first. Comparing the two classes of vessels, they are the same type and speed, and there is no great variation in size. At 16 knots, the full speed, the second Cutters were 43½ per cent less in oil consumption than the first, and at 12 knots the saving was 34.6 per cent expressed as oil per knot per ton of displacement.

Now when we stop to think that both vessels are electric drive, both vessels single screw, very much the same size and type, both had B. & W. boilers, both use oil fuel, all the measuring features were just the same, some explanation is needed. We had a great deal of data which was analyzed with the following result: Improved hull and propeller accounts for 15 of the above percentage. Temperature range mostly due to increased superheat, 11 per cent. Propelling units, that is, the efficiency of the turbines, generators, motors, etc., 8½ per cent, and the auxiliaries 9 per cent. The auxiliaries in the second ship were electrically driven and in the first ship they were steam driven, but this fact alone does not account for as much as 9 per cent.

This example shows that the best fuel economy is not necessarily a matter of the selection of type of drive, but is a combination of many factors, and the best results will follow only when accurate knowledge of them all is available.

In conclusion I would like to express the shipbuilders' feeling towards the Navy. Naval contracts are very exacting in their execution and we rely upon the unfailing courtesy and reasonableness of Navy officers. Under these circumstances all disagreements become merely contest without conflict.

TOASTMASTER: The next speaker has been a member of the Research Department of the Westinghouse Electric and Manufacturing Company since 1912, and his specialty is aptitude for designing ingenious arrangements that mystify. I am not going to explain to you these devices because that is going to be done by this gentleman himself. He is also going to give us a demonstration, and, as I understand it, show us something that is almost impossible. I am reminded of a gentleman who had been over into

Canada, and when he came back to Detroit some of his friends found it necessary to take care of him. He was mumbling to himself — "it can't be done, it can't be done." When asked what couldn't be done he pointed to an electric display sign and said — "that." The sign read — "Drink Canada Dry."

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It is my pleasure to introduce to you Dr. Phillips Thomas of the Westinghouse Electric and Manufacturing Company.

The last speaker was DR. PHILLIPS THOMAS, of the Research Laboratories of the Westinghouse Electric and Manufacturing Company. The subject of his address was "Some Broader Aspects of Radio," which he treated from the viewpoint of development and applications of apparatus to other than strictly radio purposes, although initiated in the progress of the radio art proper. The most outstanding examples of such application have to do with the three element vacuum tube, whose discovery and development, aside from making possible the present art of broadcasting, is fundamentally back of all progress in talking movie and television work, as well as of the modern satisfactory condition of long distance telegraphy and telephony.

Two pieces of apparatus rather closely allied to the vacuum tube, and developed in the course of laboratory work with such tubes and their modifications and control, are the Knowles Photo-glow tube and the Knowles Grid-glow tube. The former was a quite accidental outgrowth of work looking towards a constant voltage device for standardizing or stabilizing the voltage output of socket power devices. Mr. Knowles found that there was a small difference on the voltage necessary to pass current through a certain tube, depending on whether the tube was in darkness or was illuminated by strong light. The photo-glow tube, resulting from this discovery, is capable of passing a considerable amount of current when illuminated above a threshold value of light; when the incident light falls below this value, the current passed by the tube drops to substantially zero, so that the tube so used constitutes a sensitive relay capable of passing enough current to actuate a quite rugged mechanical relay without the need of interposed amplification.

Several applications of this tube were described, such as automatic control of ventilation of a long vehicular tunnel depending on the instantaneous number of cars in transit,—the entering and leaving cars being differentially counted by interception of light falling upon photo-glow tubes; the automatic regulation of smoke output from a power plant boiler room; the sorting of tin-plate by reflection from its surface, and the like. Its application to the automatic control of traffic at a major-minor intersection was described and demonstrated with the aid of a small model of such an intersection, equipped with traffic signals of the conventional kind. In this case the traffic signal remains green for the main street unless and until a car approaches on the side street. A photo-glow tube is so arranged at the stop line on the side street that the car stops in a position to shut off the light normally falling upon the cell. When this happens, the traffic signal motor is started up and puts the lights through one complete cycle, stopping again on main green unless a second car is intercepting the light beam, in which case the traffic signal goes through a second complete cycle, and continues the regular cycle operation until the side street is clear, when it stops once more on main highway green. This application, about to be tried out in actual traffic control, is expected to more than treble the volume of main highway traffic passing the intersection in a given time, while still allowing cross traffic the right-of-way as often as necessary.

The grid-glow tube was developed in response to the demand for an ultra-sensitive relay.* Its use enables the starting and stopping of a current of the order of 100 milliamperes, by the opening and closing of an auxiliary or grid circuit carrying less than one-millionth of an ampere. Its action like that of the photo-glow tube, is discontinuous; both tubes are similar to mechanical relays in this respect. It can be controlled by variation of a small capacity connected to the grid, as well as by variation of resistance in the grid circuit. It has the largest amplification constant of any relay yet developed, of the order of 100 million to one, i. e., the controlled current may be 100 million times as large as the controlling current.

* D. D. Knowles, "The Grid Glow Tube Relay"—The Electric Journal, April, 1928, page 176.

Several applications of this tube were described, such as its use as a burglar alarm at a bank vault or in a store window to detect the removal of anything from the window; the counting of manufacturing operations; the automatic detection of individual manufactured pieces more than a certain amount oversize, and the like. The speaker described and demonstrated its use in conjunction with a one-step amplifier and time-delay relay, as a means of automatically floodlighting an airport at night on the approach of an airplane, using the sound of the engine or propeller blades to actuate the device. Demonstration was also made of the original outfit used by the late Judge Gary to start the electrified steel mills at Homestead, from his office in New York.

NOTES.

1. MARINE STEAM ENGINEERING:

   (a) Naval Construction in 1928.
   (b) Progressive Trend in the Electrical Field During 1928.
   (c) Marine Engineering Development.
   (d) Beardmore-Bauer-Wach Installation on the *Brittania.*

2. MARINE INTERNAL COMBUSTION ENGINEERING:

   (a) Diesel Engine Weights.
   (b) Supercharging Without the Exhaust Turbo.
   (c) Diesel Engines and the French Navy.
   (d) A High Power Motor Boat Engine.
   (e) U. S. S. B. S. *Courageous.*
   (f) Launch of the Chilean Submarine *Capitan O'Brien.*

3. ENGINEERING ON SHORE:

   (a) High Pressure Turbo Alternator Set.
   (b) 2660 H.P. Oil-Electric Locomotive; Canadian National Railways.

4. ENGINEERING MATERIALS AND PROCESSES:

   (a) Carboloy—A New Tool Material.
   (b) Mechanical Applications of Chromium Plating.
   (c) Steam Turbine Blading Materials.
   (d) Notes on Brass Melting.
   (e) Research Work of Messrs. Metropolitan-Vickers Electrical Company, Limited—Vibration.

5. AVIATION:

   (a) The "Question Mark."
   (b) Consolidated Petrol Plane.
   (c) Mercedes-Benz Co. Offers New Engine.

1. MARINE STEAM ENGINEERING.

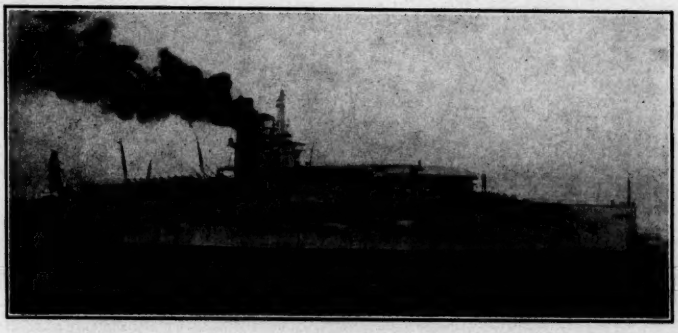
NAVAL CONSTRUCTION IN 1928.

In view of the rather loose talk that is still heard in certain quarters about "competition" or "rivalry" in naval armaments, it seems desirable to place on record one very remarkable fact. At the present moment there is not a single warship exceeding 10,000 tons under construction in any part of the world, nor will any warship above that tonnage be laid down for several years to come. We may say, indeed, that not for fifty years have international naval armaments been restricted to so modest a basis as they are today. Capital ship construction is at a complete standstill. Cruisers are being built, it is true, but the total number is by no means large, the maximum displacement is 10,000 tons, and some of the vessels are much smaller than this. Even in the lighter categories *i.e.*, torpedo craft and submarines, the current world output is far below that of pre-war days. Moreover, the past year has witnessed no extension of building commitments at home or abroad. It is possible that, before these lines are in print, the United States Congress may have passed the bill authorizing fifteen new cruisers; but in view of the American Navy's obvious shortage of modern cruising ships, it would be unfair and irrational to cite this measure as evidence of a competitive spirit in naval armaments. In Great Britain the five-year program enacted in 1925 has been reduced by no less than three cruisers. French naval construction is proceeding systematically, but it is confined in the main to small craft, the numbers of which are apt to convey an exaggerated impression of French strength at sea. Italy and Japan are both working on replenishment programs, neither of which, however, is ambitious in scope. Two factors are responsible for the limited amount of naval shipbuilding now in progress as compared with pre-war times: First, the absence of any serious cloud on the horizon of international politics; secondly, the heavy cost of modern naval material. Nor must the influence of the Washington Treaty be ignored. Whatever the shortcomings of that covenant may be, it has certainly imposed an effective brake on the multiplication of heavy fighting ships, thereby relieving the financial burdens of the powers concerned without prejudicing the balance of strength afloat.

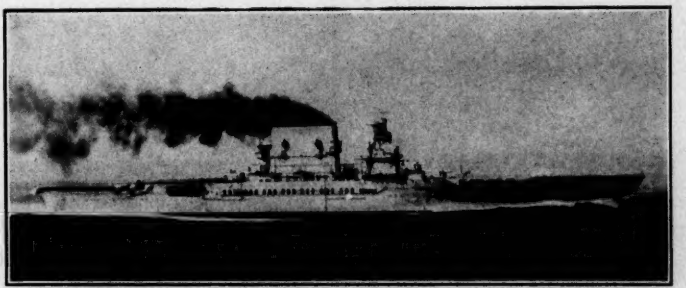
Several notable ships of the year are illustrated in one of our supplements today. We have to thank Dr. Oscar Parkes, joint editor of Jane's "Fighting Ships," for the originals from which our blocks were made.

THE BRITISH EMPIRE

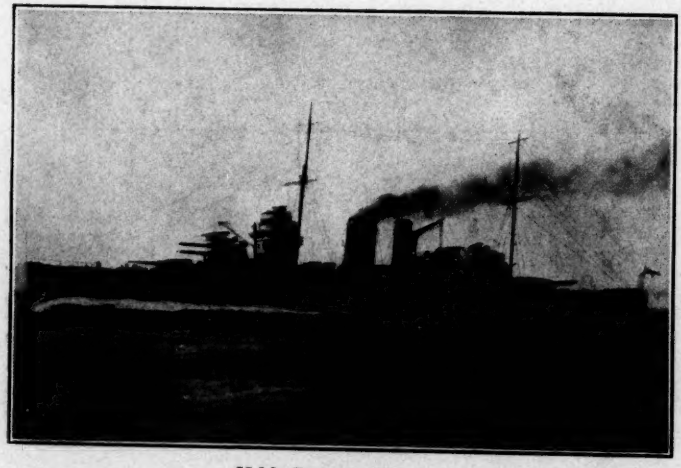
The most notable event of the year was the completion of our first group of post-treaty cruisers, as also of the two Australian ships of this class, and the—reconstructed—aircraft carrier *Courageous*. Following the delivery of the *Berwick*, *Cornwall*, and *Cumberland* between September and December, 1927, the *Suffolk* was commissioned in January, 1928, and the *Kent* in the following month. All five ships, designed by Sir E. T. d'Eyncourt, are now serving on the China Station. While this type of 10,000-ton cruiser has been a target for criticism on the score of its vulnerability, it has merits which do something to compensate for this admittedly serious yet unavoidable defect—one that is common, by the way, to all cruisers designed under Treaty rules. The *Kent* and her sisters probably have better seakeeping qualities than any previous British cruisers. Their steaming radius at economical speed is 10,500 miles. They have a very powerful armament,



H.M. Reconstructed Aircraft Carrier "Courageous"

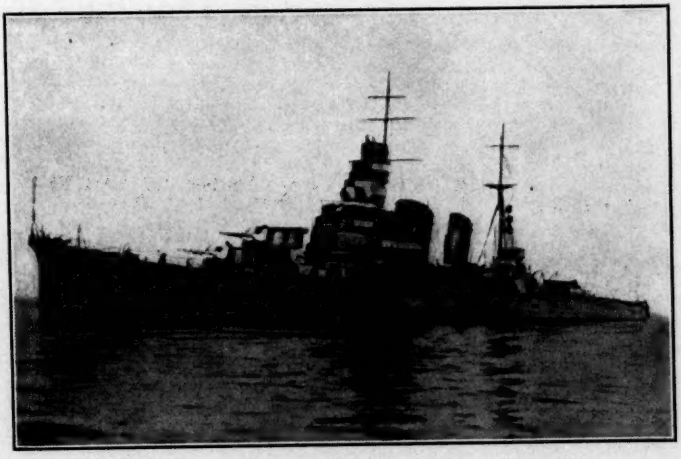


U.S.S. "Saratoga."

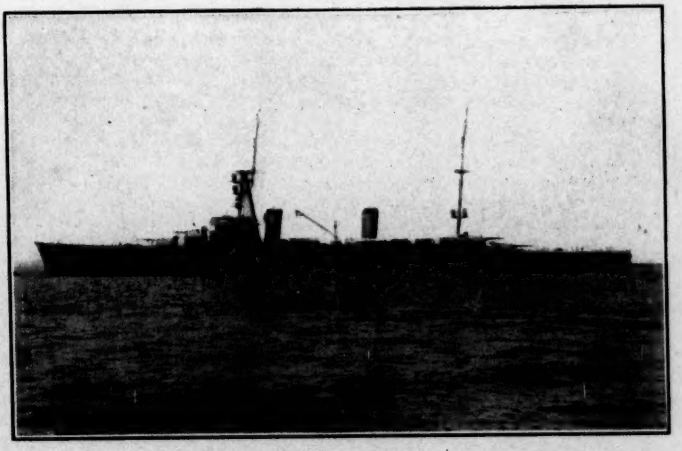


H.M. Cruiser "York."

U.S. Cruiser "Pensacola."



JAPANESE CRUISER "AOBA."



FRENCH CRUISER "TOURVILLE."

so mounted as to be capable of effective action in almost any weather; they have been shown to possess a margin of speed considerably over the contract figure of 31.5 knots, and their berthing accommodation is of the best. In short, they seem admirably adapted to the requirements of overseas service. But apart from their lack of protection, they have one serious drawback, viz., excessive cost. An average of nearly £2,000,000 is too high a price to pay for the numerous cruisers that are needed for imperial defense, and, parenthetically, it is much to be regretted that so large and costly a type should have been accepted as a world's standard under the Washington Treaty. No official trial figures have been published, but the *Berwick* is understood to have reached 32.35 knots on the measured mile, and press reports credited H.M.A.S. *Australia*, of the same class, with a speed of 34 knots on the last stage of her voyage from England to Sydney.

In the second group of 10,000-ton cruisers, *London, Devonshire, Shropshire, and Sussex*—for the design of which the present Director of Naval Construction, Sir William J. Berry, is responsible—certain modifications have been introduced. While the length between perpendiculars, 590 feet, is the same, the breadth has been reduced from 68 feet 4 inches to 66 feet, the external anti-torpedo bulge has been omitted, the shaft horsepower increased from 80,000 to 90,000, and the speed raised to 32 knots. Further, it is reported that oil engines have been installed for cruising purposes. If that be so, we can only say that Sir William Berry and his staff have produced a very remarkable ship, which represents a signal advance in cruiser design. In the *Kent* class it was not found possible to make provision for aircraft. In the *Londons*, however, a seaplane and a catapult form part of the eqiupment. Of the four units composing this group, the nameship and the *Devonshire* were launched in 1927, the *Sussex* on February 22, 1928, and the *Shropshire* on July 5th in the same year. The *London* having completed her trials was due to be commissioned on January 1, 1928, and will relieve the *Frobisher* as flagship of the First Cruiser Squadron, Mediterranean Fleet. In the absence of news to the contrary, it is surmised that the *Dorsetshire* and the *Norfolk*, laid down, respectively, at Portsmouth and the Fairfield yard, Govan, in 1927, are of the same design as the *London* class. The *Norfolk* was launched on December 12, 1928. The *Dorsetshire* is to go afloat on January 29th. For the present no other 10,000-ton cruisers are building in this country, but one ship of this type is projected in the Navy Estimates for the financial year 1929-30.

H.M.S. *York*—see Supplement—laid down at Palmer's yard, Hebburn-on-Tyne, in May, 1927, and launched by the Duchess of York on July 17th last, is the first of an intermediate type of cruising ship which may eventually become the standard so far as the British Navy is concerned. Her principal characteristics are as follows: Length between perpendiculars, 575 feet; breadth, 57 feet; displacement, without fuel, 8400 tons; geared turbine machinery of 80,000 S.H.P. for a speed of 31.25 knots; protection, a 2-inch deck over vital parts; armament, six 8-inch guns, four 4-inch A.A. guns, six torpedo tubes. An auxiliary Diesel plant for use at cruising speed is believed to be installed. Two seaplanes are to be carried on catapults. One has only to compare the *York* with the *Raleigh* class to realize what a tremendous advance has been made in cruiser design in the space of twelve years. The *Exeter*, a second ship of the *York* class, was begun at Devonport last August. A third and fourth are about to be laid down at Devonport and Portsmouth, respectively, and two further units of the class are included in the program for 1929-30.

The *Courageous*, illustrated herewith, originally a light battle-cruiser, was taken in hand for conversion at Devonport in June, 1924, and completed

in March, 1928. She has been rebuilt on much the same lines as the *Furious*, except that the boiler upstakes lead into a vertical funnel instead of a horizontal duct. In her new guise the *Courageous*, from all accounts, is proving a very successful ship. The cost of reconstructing her was £2,025,800. The *Glorious*, a sister vessel, is also being converted into an aircraft carrier. Contracts for a flotilla leader, the *Codrington*, and eight destroyers—authorized in the Estimates for 1927-28—were placed with various firms in November, 1927. The leader is being built by Swan, Hunter and Wigham Richardson, and of the destroyers, two are in hand by John Brown and Co., two by Hawthorn, Leslie and Co., two by Scott's Shipbuilding Company, and one each by Thornycrofts and Vickers-Armstrongs. It is understood that the destroyers represent an improvement on the *Amazon* and *Ambuscade*. These two boats recently made a cruise to South American ports, a voyage which imposed a severe test on their qualities of seaworthiness and endurance. They are most efficient craft in all respects.

Of the six submarines ordered in 1927, all but one were launched in the past year. The first to go afloat—May 5th—was the *Odin*, built at Chatham. The *Osiris*, *Oswald*, and *Otus* are being built by Vickers-Armstrongs; the *Olympus* and *Orpheus* by Beardmores. These vessels are larger than the *Oberon*, the prototype of the *O* class, and displace 1540 tons on the surface. Their designed speed is not yet known. Six further submarines, of the 1927-28 program, were ordered last year, one from Chatham Dockyard, one from Cammell-Laird, and four from Vickers-Armstrongs. In this order their names are: *Parthian*, *Phoenix*, *Pandora*, *Perseus*, *Poseidon*, *Proteus*. Two sloops, or "fleet sweepers," of a new type, ordered under the 1927 Estimates, have been launched by Hawthorn, Leslie, the *Bridgewater*, on September 14, 1928; the *Sandwich* a fortnight later. Their leading particulars are: Length overall, 266 feet; breadth, 34 feet; mean draught, 8½ feet; "standard" displacement, 945 tons; machinery, Parsons turbines with single-reduction gearing, driving twin screws, two three-drum oil-burning boilers working at 250 pounds; designed S.H.P., 2000; speed, 17 knots. A 4-inch gun and some smaller pieces will be mounted. These ships have been designed principally for service in the East.

Two important fleet auxiliary vessels, both by Vickers-Armstrongs, were put afloat during the year, the submarine depot ship *Medway* on July 19th, the repair ship *Resource* on November 27th. Such details of the *Medway* as are known have already appeared in our columns. She is to be propelled by double-acting, two-stroke M.A.N. Diesel engines, each of 4000 H.P., the contract speed being 16 knots. The *Resource*, which was described in "The Engineer" on November 30th, has Parsons steam turbines with a total of 7500 S.H.P. It is expected that orders will shortly be placed by the Admiralty for the seventeen vessels to be built by contract under the current Estimates, *viz.*, one flotilla leader, eight destroyers, one river gunboat, two sloops, and five submarines. The remaining ships of the program—two 8400-ton cruisers, two sloops, one submarine, and one submarine depot ship—are to be built in the Royal yards. In view of the shipbuilding depression, the award of the Admiralty contracts for the current financial year is being awaited with more than ordinary interest.

JAPAN.

The outstanding events of the year were the completion of the large aircraft carriers *Akagi* and *Kaga*, the former of 28,100 tons and 28.5 knots, the latter of 28,000 tons and 23 knots. Both were laid down as capital ships, their conversion being due to the Washington Treaty. The *Akagi*, which

closely resembles H.M.S. *Furious*, measures 763 feet between perpendiculars and has an extreme breadth of 92 feet. She carries the very powerful armament of ten 8-inch and sixteen 4.7-inch guns, the heavy weapons being mounted on the broadside in turrets or casemates. The *Kaga* is 715 feet long, with a beam of 103 feet, and has the same armament as *Akagi*. Each ship can accommodate about sixty aircraft. Although Japan began building 10,000-ton cruisers in 1924, her first ship of this type, the *Nachi*, was only completed in October, 1928. The *Myoko*, launched April 16, 1927, is running her trials; the *Haguro* and the *Ashigara* went afloat, respectively, on March 24 and May 22, 1928. All four ships are identical—Length between perpendiculars, 630 feet; breadth, 57 feet; draught, 16½ feet; standard displacement, 10,000 tons; geared turbines of 130,000 S.H.P. are installed for a maximum speed of 33 knots; the main armament of ten 8-inch guns is mounted in twin turrets on the center line, three forward and two aft. There are also four 4.7-inch A.A. guns and twelve torpedo tubes. Two seaplanes are carried. These are the most strongly armed and elaborately equipped cruisers at present afloat. The arrangement of the turrets, massive bridgework, and three sharply raking funnels—the first two trunked together—give the ships an extraordinary appearance. They are credited with triple hulls and extensive armor protection, but it is difficult to believe that so many features could be worked into a hull of 10,000 tons. Four more cruisers of this class are under construction.

The *Aoba*—see Supplement—the last of two cruisers authorized in 1923, was commissioned last January. With her sister ship, *Kinugasa*, and two very similar vessels, *Kako* and *Furutaka*, built under the previous year's program, she represents an ingenious and apparently successful attempt to incorporate great fighting power in a hull of modest displacement. All four ships are of 7100 tons standard displacement, and have geared turbine machinery of 100,000 S.H.P. for a speed of 33 knots. They have a uniform main armament of six 8-inch guns. In the first two ships these guns are singly mounted in turrets along the center line, comprising two pyramidal groups at bow and stern, respectively. In the *Aoba* and *Kinugasa*, however, the six guns are paired, two of the turrets being placed forward and the third one aft. This method probably involves less weight, while permitting equal fire concentration. Characteristics of this class are the wave-lined hull, massive superstructure, and the aeroplane hangar with a catapult. They are said to be very successful ships, though the abnormal deck weights tend, no doubt, to make them rather lively in a seaway. Several destroyers were launched during the year. They belong to a group of twenty-four boats included in the Fleet Replenishment Law of 1926. As first planned, they were to have been flotilla leaders of the most powerful type, with a 6-inch armament, but for reasons of economy the design was eventually modified. As completed, they displace 1700 tons, the contract speed is 34 knots, and the armament six 4.7-inch guns and nine torpedo tubes. The *Uranami*, of this class, took the water at Sasebo on November 29th, leaving only one more boat on the stocks. Further destroyers are projected. Although no submarine launchings were reported, it is certain that a number of new boats have been floated in recent months. The largest are those of the *I 53-60* class, with a surface displacement of 1650 tons, a length of 331 feet overall, and a surface speed of 21 knots. These large vessels are obviously intended for ocean cruising. It is noteworthy, indeed, that nearly all Japanese submarines built within the past few years have generous dimensions and a wide radius of action. A minelayer and four anti-submarine net-laying ships were begun in 1928.

FRANCE.

Ships completed, launched, and begun during the year included cruisers, a training cruiser, a mine-layer, and several destroyers and submarines. The *Tourville*—see Supplement—and *Duquesne*, cruisers of 10,000 tons, were delivered by the Brest and Lorient yards, respectively. These ships have been fully described in previous issues. They are engined for 34.5 knots, but on trial, when in light condition, the *Tourville* reached 36.15 and the *Duquesne* 35.3 knots. A third ship, *Suffren*, of somewhat modified design, better protection and reduced engine power, will be commissioned this month. A fourth ship, *Colbert*, is to be launched at Brest some time this year, and a fifth unit is on the stocks. They are the first high-speed cruisers to be built in France since long before the war, and the splendid steaming performance of the initial pair reflects great credit on the skill of French naval constructors and engineers. A very interesting ship is the new training cruiser, *Jeanne d'Arc*, which was laid down in the summer at St. Nazaire-Penhoët. Particulars: Length, 525 feet; breadth, 57½ feet; displacement, 6600 tons; turbine machinery of 35,000 S.H.P. for 25 knots; main armament, eight 6.1-inch guns in twin turrets disposed *en echelon*. While fulfilling in peace the function of a cadet training ship, this vessel might be useful in war as a second-class cruiser. The mine-layer *Pluton*, laid down in April at the same yard, may be not inaptly described as an improved version of H.M.S. *Adventure*, though her design is more akin to that of the German *Brummer* and *Bremse*. She will displace 5300 tons, the speed is to be 30 knots, and in addition to a large number of mines, she will carry four 5.5-inch and ten small guns. A submarine depot ship, the *Jules Verne*, was begun at Lorient in the past year. Displacement, 6000 tons; machinery, Sulzer-Diesel engines of 8000 H.P. for 18 knots. Five flotilla leaders were launched, *Bison*, *Guépard*, *Lion*, *Valmy*, and *Verdun*. They average 2700 tons, are engined for 35-36 knots, and will mount five or six 5.5-inch guns, with six torpedo tubes. Although officially rated as destroyers, these ships are super-leaders of the most powerful type. Eleven of them are now afloat, and ten more remain to be built. Several destroyers of the *Adroit* class were put afloat in 1928. They are boats with a normal displacement of 1495 tons, a speed of 33 knots, and an armament of four 5.1-inch and six tubes. In the original post-war building program, 91 submarines were included, one-third of these being coast defense units. Up to the present, about 55 boats have been built or ordered. Among them are two submersible cruisers, *Surcouf* class, which, displacing 3250 tons each, will be of the largest underwater craft in existence. The majority, however, are ocean-going boats of approximately 1550 tons, a speed of 18 knots, and a very heavy torpedo armament. The coast defense boats range from 600 to 630 tons, and have a speed of 14 knots. The *Ondine*, the first to be completed, was sunk on October 3, 1928, in collision with a Greek steamer.

ITALY.

Upon the completion of successful trials, the cruisers *Trento* and *Trieste* have joined the fleet. These 10,000-ton ships have enormous engine power and are probably the fastest cruisers so far built. Their leading characteristics are: Length overall, 642 feet; breadth, 67½ feet; mean draught, 19 feet. The machinery consists of Parsons turbines with gearing, and twelve Yarrow boilers burning oil. The output is 150,000 S.H.P., producing a speed of 36 knots. Eight 8-inch guns in turrets, sixteen 4-inch A.A. guns, and eight torpedo tubes are mounted. A light armor belt protects the water

line. Two additional cruisers of the same class are now in hand, the *Fiume* at the Stablimento Tecnico, Trieste, and the *Zara* at the Odero-Terni yard near Spezia. Four smaller cruisers, bearing the names of famous "*condottieri*," were begun during the year, the first at Castellamare dockyard and the other three at the Ansaldo yard, Sestri Ponente. They are exceedingly fast and well-armed scouts. Length, 597 feet; breadth, 57 feet; draught, 14 feet; designed H.P., 95,000 for 37 knots. Main armament, eight 6-inch guns mounted in pairs on the center line. Twelve big destroyers ordered in 1927 are approaching completion. They displace 2000 tons, are engined for 38 knots, and carry six 4.7-inch guns, with six tubes. Four destroyers of 1450 tons were ordered during the year. Alike in quantity and quality, the Italian torpedo flotilla is of the first rank. Ten submarines of 850-875 tons are under construction.

GERMANY.

The first of four armored vessels to replace obsolete battleships was begun at the Deutsche Werke, Kiel, in September. Officially designated a *Panzerschiff*, this ship appears to be a compromise between a coast defense monitor and a heavily armed cruiser. Although displacing only 10,000 tons, she is to mount six 11-inch guns, probably in triple turrets. A vaulted steel deck of considerable thickness will be worked over all vital parts, the hull will be minutely subdivided, and end-to-end longitudinal bulkheads will afford protection against underwater attack. The hull, electrically welded throughout, will, it is claimed, be of extaordinary lightness. The vessel will be driven by Diesel engines of the double-acting two-stroke type, built in the Deutsche Werke shops. They are reported to have a total output of 30,000 B.H.P. The cost of the ship, complete with armament, is estimated at £4,000,000. On May 20th the cruiser *Köln* was launched at Wilhelshaven. She is a sister to the *Königsberg* and the *Karlsruhe*, already afloat. They displace 6000 tons and have turbine machinery of 65,000 S.H.P. for a speed of 32 knots, but for moderate cruising speeds there is an auxiliary Diesel plant. Nine 6-inch guns are mounted in triple turrets, one forward and two aft, *en echelon*. Mines are also carried. These ships are very powerful for their size. A fourth unit is building at Kiel. Four 800-ton destroyers, launched at Wilhelshaven in March, are the last of a group of twelve boats sanctioned by the naval program of 1924-25.

SPAIN.

The keels of two cruisers were laid simultaneously at Ferrol in August. From the few details available they appear to be ships of 10,000 tons, with an 8-inch armament. The cruiser *Cervantes* was launched at the same yard in May. She is a replica of the *Principe Alfonso* and the *Almirante Cervera*, 7850 tons, 33 knots, eight 6-inch guns, designed by the late Sir Philip Watts. Two flotilla leaders and some submarines are in progress at Cartagena.

NETHERLANDS.

The eight big destroyers designed by Yarrow and Co., but built in Holland, are proving highly successful. The displacement is 1620 tons, and the designed speeds—36 knots light, 34 knots at full load—have been exceeded on trial. These are the first torpedo craft to be designed for carrying a seaplane and a catapult.

ARGENTINE.

Two of the three flotilla leaders ordered in 1927 from J. Samuel White and Co., East Cowes, were launched, the *Mendoza* on July 18th and the *Tucuman* on October 16, 1928. Displacement, 1520 tons; 36 knots; five 4.7-inch guns, six tubes.

CHILI.

All of the six destroyers ordered from J. I. Thornycroft and Co. are now afloat. They represent the largest foreign naval contract that has been placed in Great Britain since the war, its value being about £1,750,000. Two of the boats, *Serrano* and *Orella*, launched in January and March, completed their trials with gratifying results. The class has been fully described in our columns. Vickers-Armstrongs are building for the Chilean Government three submarines, the first of which, the *O'Brien*, was launched at Barrow on October 2nd. They are very similar in tonnage and other particulars to the British boats of the *Oberon* class.—"The Engineer," January 4, 1929.

PROGRESSIVE TRENDS IN THE ELECTRICAL FIELD DURING 1928.

By D. W. Niven.

There was a decided progressive trend in the marine electrical field during the year 1928. Most noteworthy was the entry of the all-electric passenger liner which is bound to have a far-reaching influence in the future design of such vessels.

The airplane carriers *Saratoga* and *Lexington* underwent their sea trials and, as previously expected they would do, broke all existing speed records for capital naval vessels. The *Saratoga* over a measured mile course maintained a speed of 33.42 knots. The *Lexington* maintained a speed of 30.7 knots for 72 hours, 34 minutes, between San Pedro, California and Honolulu, a distance of 2228 nautical miles. In addition, the *Lexington* broke the record for sustained speed for periods of 24, 48 and 72 hours, for any class of vessel. This record was formerly held by a commercial vessel, the S.S. *Mauretania*.

In the Diesel-electric field, there has been a steady, consistent increase in the amount of power applied to a single propeller shaft, and an expansion of its field of application. Three new types of vessels to adopt Diesel-electric drive during the year were the tunnel stern propeller type of river towboat, the packet boat, and the lightship.

In the auxiliary field, the totally-enclosed, fan-cooled motor for continuous duty became firmly established. Automatic and magnetic type of starters also gained in favor.

TURBINE-ELECTRIC DRIVE.

In the turbine-electric field of propulsion, the passenger liner *California* created the greatest interest both here and abroad. During the year that it has been in service it has established new standards of efficiency, comfort, convenience and "up-to-dateness." It has popularized the sea voyage from coast to coast navigated mostly through tropical seas as no vessel in the

history of shipping has done. The absence of noise, complete lack of vibration and steadiness of the vessel were a complete revelation to those accustomed to sea travel.

The passenger liner *Virginia*, the second of three new electrically-driven liners for the Panama Pacific Line of the International Mercantile Marine Company, was launched August 18 at the yards of the Newport News Shipbuilding and Dry Dock Company, and proceeded on its maiden voyage on December 8 to Pacific Coast ports via Havana and Panama.

The *Virginia* is practically a duplicate of the *California* except for an increase of 12 feet in length, a slight increase in passenger accommodation, and change in the boiler arrangement.

The electric propelling and auxiliary equipment is now being built for third vessel which is as yet unnamed. It is expected that this vessel will be ready for service either in December, 1929, or the following month.

A 19,000-ton turbine-electric passenger liner, *Viceroy of India*, was built in England for the Peninsula and Oriental Navigation Company for service between the ports of England, India, and Australia. The Britith Thomson-Houston Company, an associate of the General Electric Company, built the main propulsion equipment for this vessel, the first of its type to be built in England. This is the first large electrically-driven vessel ever built in England. It has a designed speed of 19 knots and is 600 feet long. The main power plant consists of two turbine-driven generators, either of which when working alone is capable of driving the ship at a 16½-knot speed.

DIESEL-ELECTRIC DRIVE.

Diesel-electric drive made rapid progress during 1928. The new fields of application which it entered and the extension of its power limit showed the soundness of its basic principle and the flexibility with which it adapts itself to a wide variety of ships.

One of the most outstanding installations is that of the M.S. *Courageous*, a converted freight vessel owned by the U. S. Shipping Board. This vessel, formerly a turbine-gear-driven vessel of 3000 shaft horsepower, was re-engined with a Diesel-electric power plant of 4000 shaft horsepower capacity. A new propeller with a designed full load speed of 60 R.P.M. was installed in place of the former propeller which operated at 90 R.P.M. The bow and stern lines of the vessel were also changed. These changes result in an increased ship speed of from 10½ to more than 13 knots. Diesel-electric drive was selected in preference to Diesel-direct drive because of its lighter weight, saving in space and lower first cost.

The main power plant consists of four Diesel engine-driven, direct-current, generators, each rated 800 kilowatts, 250 R.P.M., 385 volts. On the end of each main generator shaft is connected an auxiliary direct-current generator of 100 kilowatts capacity, for furnishing power for excitation and the ship's auxiliaries and lights.

The main propelling motor, directly connected to a single propeller shaft, is of the double-motor type, and is rated 4000 shaft horsepower, 600 R.P.M., 1500 volts.

Three light ships, operated by the Bureau of Lighthouse Service, were equipped with Diesel-electric drive, the first of their type to be so equipped. Heretofore, lightships were powered with steam propelling equipment for use in navigating between their station and the home port, and also to drive ahead against a storm in order not to drag the anchor. Diesel-electric drive, because of its low fuel consumption, permits a much larger stay at the station and also gives an immediate reserve of power for use in emergencies.

Power from the main generating set is also used to operate the very powerful anchor windlass equipment installed on these ships.

In the latter part of the year, work was commenced on the construction of Diesel-electric propulsion and auxiliary equipment for three additional lightships for service on the east coast of the United States. These will be duplicates of the first three.

The Diesel-electrically-driven packet and freight boat, *Edward Farrington*, operated by the Middlesex Transportation Company, is a good example of how electrification can be used to meet the specific needs of domestic merchant marine. This small craft, which has an overall length of 132½ feet, is propelled by a 400-horsepower motor which gives the vessel a speed of 12 knots. The boat is called upon to navigate congested harbors and therefore makes excellent use of the pilot house control. All the auxiliaries are completely electrified. The boat is provided with an electric hoist which is also operated from the bridge.

There has also been an extension in the field of application of Diesel-electric drive on river tow boats of the propeller type. Two such boats were built for use in transporting steel products along the Warrior River in Alabama, for the Tennessee Coal, Iron and Railroad Company of Birmingham, Alabama. The new boats are of the tunnel stern, twin screw type. The main power plant consists of two Diesel-driven direct-current generators, each rated 335 kilowatts, 250 volts, 250 R.P.M. The main propelling motors, directly connected to the propeller shaft, are the double type, and each is rated 400 horsepower at 140 R.P.M. Power for auxiliaries and lighting, as well as for excitation for the main generator and propelling motors, is furnished by two 40-kilowatt, 120-volt, direct-current, auxiliary generators driven directly from the main generator shaft. Diesel-electric drive was adopted for these boats in order to obtain higher efficiency and better maneuvering qualities. They are used on the Warrior River, which is a tortuous one, having many sharp bends and which is relatively shallow with a swift current. These boats may be operated either from the bridge or engine room as desired.

The Norfolk County Ferries of Portsmouth, Virginia, have selected Diesel-electric drive for their new automobile and passenger ferry boat which is to ply between Portsmouth and Norfolk. The power plant consists of two Diesel engine-driven, direct-current generators, each rated 270 kilowatts, and a propelling motor of the double type rated 670 brake horsepower.

The combination harbor and sea tugs, *Chagres* and *Trinidad*, which are the highest powered Diesel-electrically driven tugs in the world, were placed in service the early part of this year. These boats, which are owned and operated by the Panama Canal, have a capacity of 108 tons of Diesel fuel oil, sufficient for a cruise of 25 days, and a range of approximately 7000 miles. They may thus be used in case of emergency for servicing or towing disabled vessels at sea. They are each equipped with a 500-watt radio transmitter, with a range of 100 miles at night, for use when engaging in sea service. The tugs can also be used for fire fighting, being equipped with motor-driven pumps of a capacity of 1000 gallons per minute at a pressure of 100 pounds square inch.

In ordinary service around the Canal Zone, these tugs are used for towing barges from the dredges to the dumping grounds at sea, and for assisting vessels through the locks. The auxiliary equipment is completely electrified and consists mainly of a powerful capstan and anchor windlass of the combination type, and an automatic towing machine with in inhaul capacity of 75 feet per minute at 25,000 pounds; an electric steering gear, and miscellaneous auxiliaries in the engine room, such as pumps, blowers and compressors. The tugs have also a refrigerating plant.

The main propelling motors are of the double type and they are built to deliver 900 shaft horsepower continuously at 1450 amperes and 500 volts. The operating speed range at full power is 115 to 150 R.P.M.

The tugs were given an eight-hour dock test at 750 shaft horsepower, and also a sea test at 750 and 900 shaft horsepower, previous to their acceptance. The machinery passed all tests easily.

The Compagnia Generale Di Electricita of Italy is undertaking the Diesel-electrification of a combination car and auto ferry for service between Messina and Reggio on the Straits of Messina, to be operated by the Italian Government Railways. This ferry will have the distinction of being the highest-powered electric ferry to be built in the world to date.

The propelling equipment consists of six main direct-current generators which are to be directly coupled in pairs to three Diesel engines, and two double propelling motors of 2250 shaft horsepower capacity each. The ferry is to be of the twin screw type, driven from one end only, and having a total rating of 4500 shaft horsepower. The control equipment is to be built in America by the General Electric Company at Schenectady.

Another step in the electrification of water transportation facilities in New York harbor was taken by the State of New York in its decision to provide two more electric ferry boats to serve the metropolis. Two double-end, steel, Diesel-electric boats are now being built to run between the city and the Manhattan State Hospital on Ward's Island. These will make a total of 12 electric ferry boats operating in New York harbor. There are in service now six Diesel-electric craft, operated by Electric Ferries, Inc., and four of the turbine-electric type, operated by the city. The four turbine-electric ferries have G.E. equipment.

The power plant on each will consist of two six-cylinder, vertical, single-acting, four-cycle, air-injection Diesel engines built by the Winton Engine Company. Each engine will be rated 250 brake horsepower, and will drive a direct-current generator rated 160 kilowatts, 250 volts, at 325 R.P.M., shunt wound. Complete electric equipment will be furnished by the General Electric Company.

For the operation of auxiliaries, lights, etc., each boat will have two direct-current generators, each rated 20 kilowatts, 125 volts, at 325 R.P.M., compound wound. The auxiliary generators will be mounted on shaft extensions of the main generators.

Each boat will be propelled by a direct-current, double propulsion motor rated 400 horsepower, 180 R.P.M., 500 volts. This motor will consist of two units, each rated 200 horsepower, 180 R.P.M., 250 volts, shunt wound, and mounted on a single shaft.—"Marine Journal," January 1, 1929.

MARINE ENGINEERING DEVELOPMENT.

The end of the year has always been regarded as a convenient time in any sphere of human activity for surveying the present position and the progress made during the past twelve months, and it will not, therefore, prove inappropriate if we review the position of the marine engineering industry as it exists at the present time, at the same time endeavoring to visualize the more important developments which have occurred during the past year. The figures published by Lloyd's Register of Shipping showed that at June, 1928, of the world's shipping under construction, 1,138,463 tons were steamships, as against 1,500,544 tons of motorships, figures which would appear to prove that the Diesel engine was regarded as being superior to the steam engine for the propulsion of ships. These, however, are the figures for

ships being built all over the world, and they include those of such countries as Scandinavia and Italy, where, owing to the absence in any large quantities of coal as a native fuel, it becomes more economical to make use of the engine which utilizes heavy oil. In this country, on the other hand, not only has the tonnage of motorships under construction never exceeded that of steamships, but there is an undoubted revival in the demand for the coal-burning vessel. A study of the columns, "Orders Placed and Pending," which have appeared each week in this journal and which, it is very graitfying to note, have shown signs of increasing in number, will serve to show the extent to which shipowners are adopting the steamer in preference to the motorship; and while this is, no doubt, due to the fact that in many services power obtained from coal is relatively cheaper than power obtained from oil, it is also in a certain measure due to the fact that the overall efficiency of the steam engine is gradually being brought nearer to that of the Diesel engine, thus bringing the balance of cost more in favor of the steamship than hitherto.

As indicating, further, the interest which is being taken in the question of the revival of the steamship, it is not without significance that both before the North-East Coast Institution of Engineers and Shipbuilders and the Institution of Engineers and Shipbuilders in Scotland, the presidential address was concerned mainly with the development of the steam engine, Mr. Maurice Gibb dealing with the improvement of the reciprocating steam engine, while Mr. R. D. Moore dealt more generally with the problems of the more economical utilization of coal on board ship. With reference to the improvement of the reciprocating steam engine, it is recognized that, within limits, a considerable increase of efficiency can be obtained by the use of steam having a high initial pressure, and a considerable amount of superheat above saturation temperature. This, however, tends to reveal the inherent weakness of the slide valve for controlling the supply of steam to and exhaust from the cylinders, and the introduction of the poppet-valve engine marks a definite endeavor to surmount this difficulty. At the low-pressure end the use of the steam turbine, as exemplified by the popular Bauer-Wach system, enables the advantages of the combination of reciprocating engine and turbine to be obtained with the moderate powers required for the propulsion of single-screw steamers. In the stokehold the use of high-pressure steam has led to the wider adoption of the water-tube boiler, although where the pressures are not excessive the cylindrical return-tube type of boiler is still very extensively employed. Considerable advance has also been made in the use of mechanical methods of firing the coal into the furnace. The use of the mechanical stoker, particularly with boilers of the water-tube type, in which the larger furnace renders their application very suitable, leads to a considerable reduction in the personnel of the stokehold, and the use of pulverized coal, while it entails the installation of machinery for pulverizing the coal prior to forcing it into the furnaces, yields the same economy as regards personnel, together with a most efficient and better regulated generation of steam. The advantages of mechanical stokers and pulverization are sufficiently well recognized to warrant extensive experiments both on water-tube boilers and on the more usually installed Scotch boilers, but so far no definite attempt appears to have been made to obtain the well-known advantages of using low-grade coal in conjunction with one or other of the various systems of pulverization.

It must not, however, be imagined that the Diesel engine designers have remained inactive in face of the growing challenge of the steam engine. Various attempts have been made during the past year to improve the efficiency of this type of engine, one of the most notable of which is to be

found in the adoption of the principle of supercharging. In particular, the use of the exhaust gas turbine for driving the supercharging blower, a system which is associated with the name of the Swiss engineer, Büchi, has been shown to yield a considerable increase of power for a given size of engine, or alternatively a smaller engine for a given power. It is recognized, too, that the weight of the Diesel engine often militates against its wider adoption, and in many designs means are being employed for reducing the weight, and with it the overall dimensions of the engine. This can be readily effected by the use of higher speeds of rotation, and while certain comparatively high-speed engines are direct-coupled to the propeller shafts, the use of gearing such as is represented by the hydraulic and the electric drive enables the speed of the main engines to be fixed without any direct relationship to that of the propellers. The Diesel engine has also been developed in the direction of increasing the power per cylinder, thereby enabling it to challenge the steam turbine as a suitable system of propulsion for the largest and fastest types of passenger liner.

It will be recognized, therefore, from the foregoing brief survey, that despite the rather unhappy position of the shipbuilding industry as a whole, the marine engineering profession is very much alive. This friendly rivalry between the various systems of propulsion is entirely to the good, since it means that no matter what system the shipowner finally decides to employ, he is assured that he will obtain the highest efficiency which that particular system is capable of yielding, thereby enabling him to operate and maintain his ships at the lowest possible cost.—"Shipbuilding and Shipping Record," December 27, 1928.

BEARDMORE-BAUER-WACH INSTALLATION ON THE "BRITANNIA."

EXHAUST TURBINE WITH QUADRUPLE-EXPANSION RECIPROCATING ENGINE YIELDS AN ECONOMY OF 20 PER CENT, REPRESENTING A SAVING OF £7,350 PER ANNUM.

We referred briefly in a recent issue to the Beardmore-Bauer-Wach installation which has just been fitted to the Anchor liner *Britannia*. The installation is of particular interest because not only does it represent the pioneer installation which William Beardmore & Co., Ltd., Dalmuir, have constructed, but because the vessel on which the new equipment has been installed is only two years old, having been built in 1926 by Alexander Stephen & Sons, Ltd., Linthouse, when she was fitted with a quadruple-expansion reciprocating engine, having cylinders 29½ inches, 42¼ inches, 60¾ inches and 87 inches in diameter, with piston stroke 54 inches and superheated steam supplied by oil-fired boilers, making her one of the most economical reciprocating-engined steamers afloat.

The principal dimensions of the *Britannia* are as follows:

Length between perpendiculars, feet	460
Breadth, moulded, feet	59
Depth, moulded, feet	29.5
Gross tonnage, tons	8,464
Speed knots	13½

The Beardmore-Bauer-Wach exhaust turbine, which works in conjunction with a Beardmore-Vulcan hydraulic coupling and double reduction

toothed gearing of the single helical type, has been designed to work with the existing quadruple-expansion reciprocating engine, the two drawings reproduced show the arrangement of the engine room before and after the conversion.

The main drive for the reciprocating engine is of the quill type, so permitting the main gear wheel on the line shaft being rigidly held in its main bearings irrespective of normal wear down in the reciprocating engine crankshaft. An oil strainer is fitted to extract the oil from the exhaust steam from the low-pressure cylinder of the reciprocating engine, the steam then passing to an oil-controlled switch valve which diverts the steam either directly to the condenser when the turbine is not required to operate, or to the turbine as required under normal operation. The oil coupling is filled and maintained full of oil by a Weir's oil pump, the speed of which is regulated from the lubricating oil tank, and the oil control is such that the clutch must be full, the turbine being thus connected to its drive before the switch valve diverts the steam from the condenser to the turbine.

The drawing reproduced on page 105 gives the details of the exhaust turbine, the hydraulic coupling and the speed reduction gearing. Referring to this drawing, A is the turbine driving through the enclosed forced lubricated shaft B on to pinion C of the first reduction gearing, of which the gear wheel is E, the center of which forms the Beardmore-Vulcan hydraulic coupling F and G, F being the driving and G the driven member. The second reduction pinion H on an outer sleeve of the spindle of the primary wheel is driven by the portion G of the hydraulic coupling, this pinion driving the main wheel J, which is mounted on a sleeve K and coupled up at L M to the main shaft line X.

TRIAL TRIP.

The trials of the *Britannia* were run on Friday, September 21, in the Firth of Clyde, and proved successful in every way. A summary of the results obtained is given in the tables overleaf, from which it will be seen that an economy in fuel consumption of about 20 per cent was obtained.

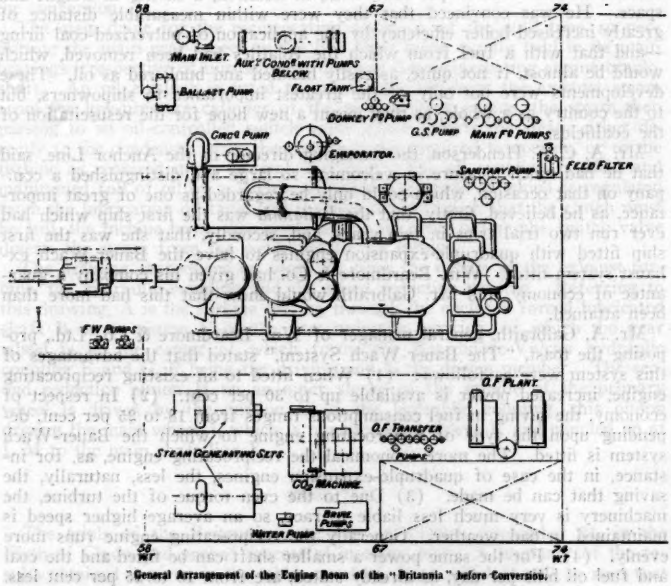
A notable company of shipowners and superintendent engineers attended the trials, and at a luncheon on board, which was presided over by Mr. A. C. F. Henderson, deputy-chairman and managing director of the Anchor Line, Mr. Val B. Stewart, a director of William Beardmore & Co., said it was noteworthy that the owners of the *Britannia* had made this change in the machinery installation of a vessel which was only two years old. The ship had the most economical steam reciprocating machinery that could be devised when she was built, but the installation had been drastically altered, and the fuel bill cut down by 20 per cent. When turbine propulsion was introduced some owners were content if they gained a 10 per cent advantage. With the increased cost of fuel since these days, the latest development offered shipowners a very remunerative investment. In an older ship than the *Britannia* the value of the investment would be increased by the greater length of useful life which could be given to the vessel. The Beardmore Company had, during the past two years, given a large amount of time and attention to the question of increasing the efficiency of steam propulsion. If as much time and thought had been applied all round to the steam engine as had been given to the Diesel engine in the past ten years, the former would have been before now in at least the position to which his firm had brought it. The Beardmore-Caprotti valve gear permitted higher steam pressures and superheat to be used than was possible with the slide valve or piston valve engine, and hence, if full advantage were taken of this develop-

ment, coupled with the Bauer-Wach installation in a new *Britannia*, it was certain that the economy to be obtained over the original installation would amount to well over 25 per cent, with, in addition, a saving in weight and space. He was convinced that they were within measurable distance of greatly increased boiler efficiency by the application of pulverized-coal firing —and that with a fuel from which the volatiles had been removed, which would be almost, if not quite, as easily handled and bunkered as oil. These developments were not only of the greatest importance to shipowners, but to the country as a whole, as they meant a new hope for the resuscitation of the coalfields.

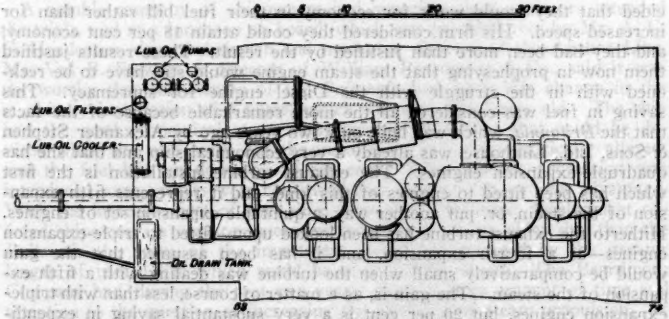
Mr. A. C. F. Henderson, the managing director of the Anchor Line, said that he had much pleasure in welcoming so large and distinguished a company on that occasion, which could only be regarded as one of great importance, as he believed, firstly, that the *Britannia* was the first ship which had ever run two trial trips in two years, and, secondly, that she was the first ship fitted with quadruple-expansion engines to have the Bauer-Wach exhaust system fitted. Wm. Beardmore & Co. had given his company a guarantee of economy, and Mr. Galbraith would show that this had more than been attained.

Mr. A. Galbraith, general manager of Wm. Beardmore & Co., Ltd., proposing the toast, "The Bauer-Wach System," stated that the advantages of this system were as follows: (1) When fitted to an existing reciprocating engine, increased power is available up to 30 per cent. (2) In respect of economy, the saving in fuel consumptions ranges from 18 to 25 per cent, depending upon the type of reciprocating engine to which the Bauer-Wach system is fitted. The more economical the reciprocating engine, as, for instance, in the case of quadruple-expansion engines, the less, naturally, the saving that can be made. (3) Due to the even torque of the turbine, the machinery is very much less liable to race, so an average higher speed is maintained in bad weather. Generally the reciprocating engine runs more evenly. (4) For the same power a smaller shaft can be fitted and the coal and fuel oil bills per day, as already stated, are from 18 to 25 per cent less.

The directors and technical representatives of the Anchor Line had decided that they would work for economy in their fuel bill rather than for increased speed. His firm considered they could attain 18 per cent economy, and they had been more than justified by the result. These results justified them now in prophesying that the steam engine would still have to be reckoned with in the struggle with the Diesel engine for supremacy. This saving in fuel was considered all the more remarkable because of the facts that the *Britannia*, which was built only two years ago by Alexander Stephen & Sons, Ltd., Linthouse, was already a very economical ship and that she has quadruple-expansion engines. The exhaust turbine installation is the first which has been fitted to engines of this kind, and it represents fifth expansion of the steam, or, put another way, a quintuple-expansion set of engines. Hitherto the exhaust turbine has been looked upon—fitted to triple-expansion engines—as a fourth expansion, and it has been assumed that the gain would be comparatively small when the turbine was dealing with a fifth expansion of the steam. The gain is, as a matter of course, less than with triple-expansion engines, but 20 per cent is a very substantial saving in expenditure. It means a decrease from 50.5 tons of fuel per day to 40.5 tons. Ten tons saved per day on five round voyages of 42 days—from the Clyde to Bombay and back—represents a saving of more than £7,350 per annum, reckoning fuel at £3 10s. per ton.



General Arrangement of the Engine Room of the "Britannia" before Conversion.



The Quadruple-Expansion Engine of the "Britannia" after Wm. Beardmore & Co. Ltd. had fitted the Beardmore-Bauer-Wach Exhaust Steam Turbine, the Double-Reduction Gearing, and the Beardmore-Vulcan Hydraulic Coupling.

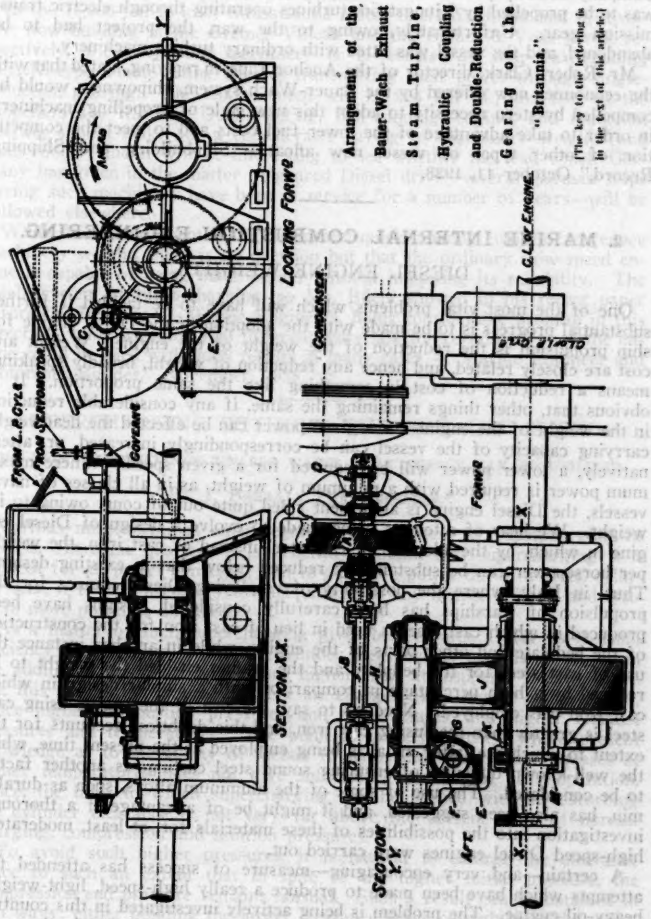
Time	*Mean, 8:49 p.m.-12:49 a.m. Reciprocating Engine Only.*	*Mean of 3 Hours Reciprocating Engine and Exhaust Turbine.*
Boilers—		
Pressure	207	211
Temperature	414.4	398
Superheat	24	6
Main steam, boiler side of engine stop valve—		
Pressure	208.8	211
Temperature	433	428
Superheat	41½	35
Receiver pressures—		
1st I.P.	115.4	85
2nd I.P.	43	33
L.P.	7.8	7.6
L.P. cylinder exhaust pressure—		
Before separator	21.75	14.5
After separator	.....	.....
Turbine—		
Inlet—		
Pressure	.....	13.1 in.
Temperature	.....	.....
Exhaust—		
Pressure	.....	.....
Temperature	.....	.....
Vacuum gauge	26.83	28.04
Kenotometer	3.4	2.24
Barometer	30.23	30.28
Temperature suction from condenser	94° F.	93.50° F.
Mean pressures—		
H.P.	70.2	70.2
1st I.P.	43.66	31.9
2nd I.P.	18.3	11.76
L.P.	8.94	5.44
I.H.P. reciprocating engine—		
H.P.	1,123	1,113
1st I.P.	1,448	1,053
2nd I.P.	1,240	790
L.P.	1,215	751
Total	5,026	3,707
Equivalent I.H.P. turbine	.....	1,315
Total I.H.P.	5,026	5,022
R.P.M.—		
Engine	85.46	85.08
Turbine	.....	.....
Cut-offs—		
H.P.	0.68	0.52
1st I.P.	0.6	0.595
2nd I.P.	0.6	0.56
L.P.	0.6	0.56
Referred mean pressure	36.2	26.9
Number of boilers in use	4	4

Time	*Mean, 8:49 p.m.-12:49 a.m. Reciprocating Engine Only.*	*Mean of 3 Hours Reciprocating Engine and Exhaust Turbine.*
O.F. burners—		
Size	20	12 and 14
Number in use	16	16
O.F. pumps D.S.	16.9	12
O.F. pressure	112	99
O.F. temperature	224	206
Air pressure—		
Fan	2.2	1.56 in.
Furnaces	0.7	9/16 in.
R.P.M. fan	292	251
Feed temperature—		
Hotwell	96° F.	96° F.
Feed pump	197° F.	201.5° F.
D.S. feed pump	800	685.0
R.P.M. circulating pump	297	267
Sea temperature	56° F.	56° F.
Circulating discharge temperature	.....	.....
Air temperature entering furnaces	272° F.	252.5
Temperature of gases—		
At uptakes	626	590.0
At base of funnel	492	452.0
Lubrication oil pressure—		
Regulating valve	36.6	40.0
Filling to clutch	0	11.0
Turbine bearings	12	12.25
Gear-case bearings	15	15.8
Oil fuel—		
Lb. per hour	5,240	4,178
Lb. per I.H.P. hour	1.04	0.832
Ejector steam pressure	.....	127
Temperature of boiler room	97	95

This performance, however, by no means reaches the limit of steam economy, even with normal boiler pressures and temperatures. In a new vessel the same total service power could be developed by the following methods, each of which would afford considerable savings in comparison with the original installation: (1) Beardmore-Caprotti valve gear, without the exhaust turbine, would show a gain of 40 tons in weight, from 6 to 8 feet in length, and in the annual fuel bill of £3,675. (2) With Beardmore-Caprotti valve gear and Bauer-Wach exhaust turbine, there would be a saving of 100 tons in weight, from 6 to 8 feet in length, and in the annual fuel bill of £8,452. (3) High-speed triple-expansion engine fitted with Beardmore-Caprotti valve gear running at 250 R.P.M. through the Beardmore-Vulcan clutch to 80 R.P.M. on the propeller shaft; in conjunction with an exhaust turbine, would give a saving of 6 to 8 feet in length, 150 tons in weight, and in the annual fuel bill of £9,187.

The latter combination would also give a saving in headroom of at least 12 feet.

Just as the slow-running turbines were being displaced by smaller and higher-speed turbines, the fast-running Beardmore-Caprotti, Bauer-Wach installation, with pulverized coal as fuel, would bring steam back into the front rank. He thought the Clyde could fairly claim to have done something



Arrangement of the Bauer-Wach Exhaust Steam Turbine, Hydraulic Coupling and Double-Reduction Gearing on the "Britannia."

[The key to the lettering is in the text of this article.]

to resuscitate both the steam engine and the British coal industry, and, he added, as an interesting fact, that while so much was being heard now of the turbo-electric drive in marine propulsion, as far back as 1913 the Cunard Company actually placed with Beardmore & Co. an order for a liner which was to be propelled by Ljungström turbines operating through electric transmission gear. Unfortunately, owing to the war, the project had to be abandoned, and the vessel was fitted with ordinary turbine machinery.

Mr. Robert Clark, director of the Anchor Line, in replying, stated that with the economies now offered by the Bauer-Wach system, shipowners would be compelled by stern necessity to adopt this new style of propelling machinery in order to take advantage of the lower fuel costs and to meet the competition of other types of vessel now afloat.—"Shipbuilding and Shipping Record," October 11, 1928.

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2. MARINE INTERNAL COMBUSTION ENGINEERING.

DIESEL ENGINE WEIGHTS.

One of the most vital problems which will have to be tackled if further substantial progress is to be made with the adoption of the Diesel engine for ship propulsion is the reduction of the weight of the engine. Weight and cost are closely related, and hence any reduction of weight, broadly speaking, means a reduction of cost in something like the same proportion. It is obvious that, other things remaining the same, if any considerable reduction in the weight of the engine for a given power can be effected the deadweight carrying capacity of the vessel can be correspondingly increased, or, alternatively, a lower power will be required for a given speed. Where maximum power is required with a minimum of weight, as in all classes of naval vessels, the Diesel engine is at present ruled quite out of court owing to its weight. We hear of attempts being made to evolve a design of Diesel engine in which, by the adoption of cast steel instead of cast iron, the weight per horsepower can be substantially reduced below that in existing designs. Thus, in Italy, where the possibility of employing Diesel engines for the propulsion of warships has been carefully considered, designs have been produced in which cast steel is used in lieu of cast iron for the construction of the bedplate and other parts of the engine, while in another instance the use of cast steel for the bedplate and the frames enabled the weight to be reduced by a high percentage in comparison with a similar design in which cast iron was employed. Needless to say, the cost of the engine using cast steel is greater than that using cast iron, and this doubtless accounts for the extent to which the latter metal is being employed at the present time, while the well-known difficulty of ensuring sound steel castings is another factor to be considered. The use of some of the aluminum alloys, such as duralumin, has also been suggested, and it might be of advantage if a thorough investigation into the possibilities of these materials for, at least, moderately high-speed Diesel engines were carried out.

A certain—and very encouraging—measure of success has attended the attempts which have been made to produce a really high-speed, light-weight, heavy-oil engine. The problem is being actively investigated in this country, Germany, America, and elsewhere at the present time, and already the commercial stage has been reached in several notable cases of which all engineers have knowledge. In America, a yacht has been built in which the propelling machinery consists of two "V"-type 12-cylinder engines, each developing 3000 B.H.P. at 700 R.P.M. The weight of these engines is said to be about

21 pounds per B.H.P. Recently a land type, two-stroke-cycle, double-acting, airless-injection M.A.N.-type engine of 11,700 B.H.P., was completed for peak load service in a Berlin power station. This engine runs at 215 R.P.M. and is said to weigh 55 pounds per B.H.P.

In the 16,000-ton 16-knot transatlantic motor liners *St. Louis* and *Milwaukee*, now building in the Bremer Vulcan and the Blohm & Voss yards, respectively, the propelling machinery is to consist of four fast-running M.A.N.-type double-acting engines transmitting their power through single-reduction gearing. The engine speed will be 225 R.P.M., and that of the propellers 110 R.P.M. Double-acting, fast-running, engines and reduction gearing should make for a considerable saving of machinery weight (and head room), and it will be interesting to see whether the lead which Germany has given in the matter of geared Diesel drive—several German ships having such machinery have been in service for a number of years—will be followed elsewhere.

While there is no doubt that gearing and quick-running engines can reduce machinery weight, there is no question but that the ordinary slow-speed engine is capable of being made lighter without impairing its reliability. The Büchi system of turbo-charging, so Mr. Büchi showed in his recent paper before the Institute of Marine Engineers, holds considerable promise in this direction, while we think that different materials for certain parts of the engine could be used with good results in many cases.—"Marine Engineer and Motorship Builder," November, 1928.

SUPERCHARGING WITHOUT THE EXHAUST TURBO.

NO GAIN IN EFFICIENCY UNLESS WASTE HEAT ENERGY CAN BE UTILIZED.

By J. Barraja Frauenfelder.*

Various misconceptions exist regarding the process of supercharging in Diesels. In some quarters it is generally thought that supercharging is a panacea for all power demands; that to get more power out of a given cylinder size, it is only necessary to supercharge to any degree desired, and *ipso facto* more power is obtained.

As a matter of fact, supercharging gives best results, as far as thermal efficiency is concerned, when the cylinder clearance is not disturbed, when the additional air under a pressure higher than atmospheric is introduced. But this has its limitations. Higher air charges mean higher compressions, hence higher combustion pressures and temperatures, and higher exhaust pressures and temperatures. The point is quickly reached where present knowledge as to the ability of metals to withstand such higher stresses at higher temperatures does not give sufficient guarantee of safe operation, hence, the limit to which supercharging can be pushed without disturbing the cylinder clearance is not very far above the present limit of normal charging, compression and ignition pressures.

To avoid such higher pressures, it is natural to enlarge the clearance space to such an extent that in spite of the higher initial pressure, the compression end pressure remains normal. Such a result can be obtained in two ways: either building the larger clearance space outright into the cylinder, thus compromising on the thermal efficiency when supercharging is not used, or by providing the cylinder with an unloader designed to provide a greater clearance when supercharging is resorted to. Of the two methods

* Consulting Engineer.

the first is the most logical and reliable because it involves no additional losses. The second leads into complications caused by additional radiation and transfer losses, greater contamination of the new air charge by unavoidably greater residues of burnt gases in the cylinder, mechanical tribulations and other difficulties. These complications naturally lower the final thermal efficiency more than with the first method.

GOVERNING FACTORS.

The air charge should be preheated to such a degree that the necessary compression end temperature, in any case, will be obtained. About such a working cycle the following observations are in order: Theoretically, it is possible to introduce a large air charge into the cylinder and thus increase the mean indicated pressure considerably. In practice, however, things look different.

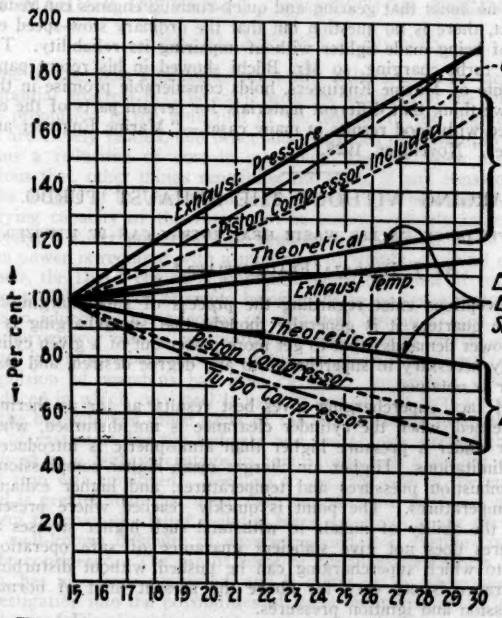


Fig. 1 Supercharging Pressure in Lbs./in² Abs.

1.—The volumetric efficiency will not increase in proportion to the supercharging pressure on account of the necessary preheating of the air.

2.—The exhaust pressures and temperatures will increase with increasing supercharging pressure and thus follows a decrease in the thermal and overall efficiencies on account of the *decrease in the ratio of expansion.*† (These

† See Magg—"Dieselmachinen"—1928.

conditions are illustrated in Figure 1, together with the theoretical increase in the fuel consumption. The theoretical increase in the *mean indicated* pressure is shown in Figure 2.)

3.—However, the necessary work to be expended in producing the air charge, which by somewhat higher scavenging pressures cannot be obtained exclusively from the energy in the exhaust gases, is not yet considered. To illustrate the percentage of total power expended in supercharging, calculatons have been made and the results plotted:

(*a*) For an air compressor driven direct by the main engine, and (*b*) For a blower driven by an electric motor with current furnished from the generator of the main engine.

As a basis for the calculations the following values which may be taken as the best obtainable in practice, averaged over quite a large number of machines, were assured.

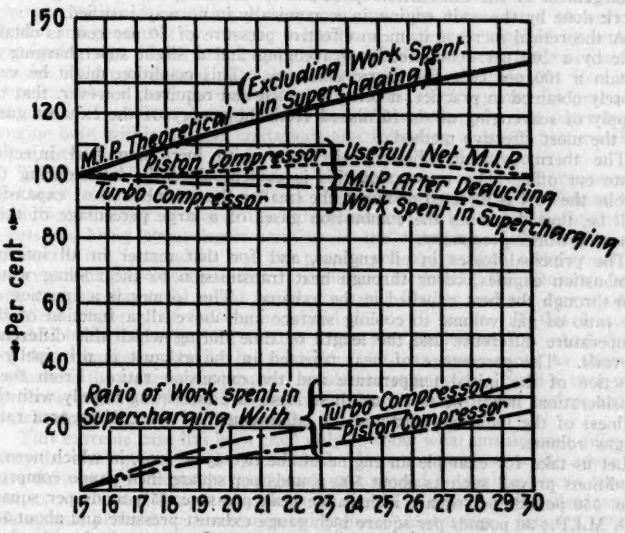


Fig. 2 Supercharging Pressure in Lbs./in² Abs.

For the Compressor:

Adiabatic efficiency	.35
Mechanical efficiency	.90
Pressure transfer drop through valves, 7 per cent.	

For the Blower:

Generator efficiency	.93
Motor efficiency	.91
Blower efficiency	.96
Adiabatic efficiency	.70

In both cases, and these values are also derived from practice, a suction pressure of 14 pounds per square inch and an air ratio of 23.79 pounds to pound of oil was assumed.

The percentage of compressor work to the unsupercharged engine indicated work is also shown in Figure 2. As shown, with such a working cycle and by the use of a blower, it is not possible to obtain any increase in the mean effective pressure, while only a negligible gain, in no way justified by the additional efforts necessary, is possible by the use of a direct driven compressor. In any case, however, quite a considerable loss in economy and efficiency is integral with this cycle.

CONCLUSIONS.

Supercharging is advantageous only when utilizing the energy in the exhaust gases. Supercharging to any considerably higher pressures, with enlargement of the combustion space and by obtaining the air charge out of work done by the main engine, is economically in no way justified.

A theoretical increase in mean effective pressure of 30 per cent is obtainable by a 100 per cent effective scavenging and a slight supercharging to obtain a 100 per cent volumetric efficiency. This condition might be very closely obtained in practice, it being assumed and required, however, that the supply of scavenging air is furnished from the energy of the exhaust gases by the most effective method.

The thermodynamic efficiency *decreases* with increasing fuel injection (late cut off). The reason for this is evident since the later during the stroke the fuel is injected or burnt, the smaller the useful ratio of expansion will be, thus depriving the combustion gases of a large percentage of their inherent working capacity.

The principal losses in oil engines, and for that matter in all internal combustion engines, occur through heat transmission to the cooling water and through the heat expelled in the exhaust. The former is a function of the ratio of gas volume to cooling surface and above all a function of the temperature difference and the length of time during which this difference prevails. The percentage of heat rejected in the exhaust is principally a function of the initial temperature and the expansion ratio. From these considerations it will be seen that these losses are increasing rapidly with the fullness of the indicator card and the enlargement of the cooling area ratio to gas volume.

Let us take for example an engine of the two cycle type, in which normal conditions prevail such as about 500 pounds per square inch gauge compression, 550 pounds per square inch gauge peak pressure, 85 pounds per square inch M.I.P.; 30 pounds per square inch gauge exhaust pressure and about 550 degrees F. exhaust temperature; also normal scavenging as required, with a fuel consumption of about .32 pound per I.H.P. hour and with a thermal efficiency of about 33 per cent. Let us assume that we wish to supercharge this engine to about 28 pounds per square inch absolute, with an engine driven compressor, and that we wish to preserve the compression pressure, hence we increase the clearance to accomplish this.

From the charts, Figures 1 and 2, we find that the M.I.P. will increase by $85 \times 1.33 = 113$ pounds per square inch theoretically, but when we deduct the work of supercharging then the net increase is only 85×1.03, or 87½ pounds per square inch.; in other words, we have *an increase of three per cent in power*. The exhaust pressure will have gone from 30 pounds per square inch to $30 \times 1.8 = 54$ pounds per square inch, the exhaust temperature from 550 degrees F. to $550 \times 1.14 = 627$ degrees F., the fuel consump-

tion from .32 pounds per I.H.P. to $.032 \times 1.24 = 00.36$ I.H.P. theoretical, or net $0.32 \times 1.57 = 0.499$ pounds per I.H.P.; in other words, an increase in fuel consumption of 56 per cent for a 3 per cent gain power. The thermal efficiency of the engine will have dropped from 0.33 per cent to $0.33 \times 0.81 = 0.267$ theoretical or $0.33 \times 0.64 = 0.21$ actual.

If the mechanical efficiency of the engine without supercharge was 75 per cent, it would be reduced to $\frac{\text{B.H.P.} + 3 \text{ per cent}}{\text{I.H.P.} + 33 \text{ per cent}} = 58$ per cent approximately.

If a turbo blower is used instead of a direct driven compressor, these values would be further depreciated.

Such supercharging installations as have been made recently with four cycle engines are not exempt from these considerations, except that for practical reasons it was desirable to obtain the net theoretical increase in power of the engine without deducting the power consumed by the supercharger to avoid installing a larger engine. In these cases blowers are driven independently by electric motors and current is supplied by separate generating sets. Such installations are justified when peak loads are not excessive, if frequent, and normal loads prevail. Furthermore, in four cycle engines 100 per cent scavenging and volumetric efficiency may be practically obtained. The above example serves as an illustration of a non-supercharged engine built within normal limitations and following accepted best standards of construction.

To illustrate what would happen if compression and peak pressures are lowered from the normal is a task impossible of verification without tests. It suffices to say that basing the thought on an ill-advised theory, lesser peak pressures bring about lesser stresses in the structure of the engine, such pressures are lowered to say 350 pounds per square inch compression and corresponding ignition pressure; by further increasing the clearance space, the compression ratio would be lowered still further and the corresponding thermal efficiency of the engine would drop still lower. If this is accomplished by an unloader still further losses may be looked for. And, finally, if the compressor should be subdivided into as many units as there are cylinders, the losses thus incurred would increase again. Such a case would probably find its thermal efficiency in the 15-20 per cent region and the mechanical efficiency well below the 50 per cent range.

This extreme case has been cited only to show what unsuspected difficulties may be encountered by the uninitiated. It is obvious that while advantages are derived from supercharging, each case should be analyzed very carefully on its merits and proper consideration should be given to the disadvantages as against probable or overestimated gains.—"Motorship," January, 1929.

DIESEL ENGINES AND THE FRENCH NAVY.

DETAILS OF MAIN AND AUXILIARY ENGINES OF VARIOUS TYPES BUILDING IN FRENCH WORKS.

Considerable progress has taken place during the last months in the adoption of Diesel engines on new French warships. Considering submarines, it is interesting to observe that the power of the Diesel engines fitted in such craft has been increasing to a great extent, and that the 19 new 1560-ton submarines now building for the French Navy are each to be fitted with two

Diesel engines to develop 3000 B.H.P. each. Two Diesel engines, each of 6000 B.H.P., will be fitted in the new 5000-ton submarine depot ship *Jules Verne*, now building at the Lorient Naval Dockyard.

Following the delivery of their first motor tanker, *Le Loing*, the French Navy now have on order two new motor-tankers, *Le Mékong* and *Le Niger*, while they are to order two Diesel-engined advice-boats in the near future. There is another direction in which the wider use of the Diesel engine on French warships is also noticeable, namely, in the fitting of auxiliary Diesel engines for electric power-generating purposes. Such plant will be fitted on the new 10,000-ton cruisers. The first application of this character was made on the cruisers *Duquesne* and *Tourville*, which have been fitted with six Chaléassière auxiliary Diesel engines, supplied by the Société Nouville des Usines de la Chaléassière. Following on recent arrangements, this firm is now in a position to construct Diesel engines of three distinct types, namely, Chaléassière two-stroke and four-stroke cycle engines, these being more especially designed for high powers, and notably for warships; Chaléassière-Werkspoor four-stroke cycle single and double-acting engines, for merchant ships; and Chaléassière-Junkers two-stroke cycle airless-injection opposed-piston engines, for moderate and small powers.

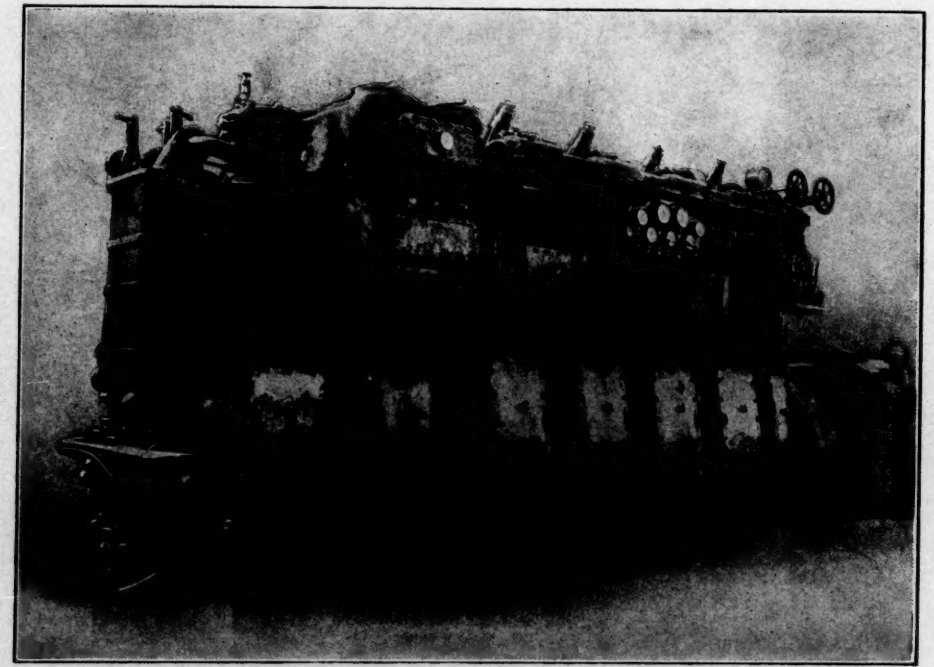
The engines referred to above as being fitted on the new 10,000-ton cruisers are of the Chaléassière two-stroke cycle type. Each engine has four cylinders 270 millimeters in diameter by a 300-millimeter stroke, and is designed to develop a normal power of 225 B.H.P. and a maximum of 270 B.H.P. at 400 R.P.M. One of these engines is shown in the illustration on this page, which shows that it drives its own injection air compressor and scavenging pump. The pistons are sea-water cooled. Each engine is direct-coupled to a 150-Kw. dynamo.—"Shipbuilding and Shipping Record," Nov. 8, 1928.

A HIGH POWER MOTOR BOAT ENGINE.

Official tests were recently made at the Fiat Works, Turin, before a commission appointed by the Royal Italian Navy, on a new *M 900* type of high-power petrol engine, built for naval motor boat service. The unit tested has a designed output of 750 B.H.P. at 1940 R.P.M., with a propeller speed of 1700 R.P.M., and the maximum horsepower of 790 was developed at 2050 R.P.M., with a propeller speed of 1800 R.P.M. The dry weight of the engine is 3950 pounds, and its fuel consumption is given as 0.55 pound of petrol per horsepower-hour, in addition to which 0.02 pound of lubricating oil per horsepower-hour is required.

The new unit consists of two six-cylinder engines, connected by gearing and mounted on a single aluminum base which forms both the crank case and the reverse gear housing. On the top of the gear casing is a column carrying all the controls and instruments. The cylinders each have a bore of 165 millimeters (6.496 inches), with a stroke of 170 millimeters (6.693 inches), and are cast in blocks of three, both the cylinders and jackets being made of cast iron. The combustion chambers have flat tops with vertically arranged twin inlet and exhaust valves operated by two camshafts. The valve gear is of the bridge type, generally similar to that which is employed in Fiat type aircraft engines. There are four double inverted carburetters, which are fed by pumps, and two ignition plugs are fitted to each cylinder.

The reversing gear and speed-reducing gear is of the Dohmen-Leblanc friction clutch type, with one ahead and one astern running clutch. These clutches, together with thrust bearing and the cardan joint for the inclined propeller, form a neat group at the front of the engine. Between the two



FOUR-CYLINDER 225-B.H.P. CHALÉASSIÈRE TWO-STROKE CYCLE ENGINE AND GENERATOR, AS FITTED ON THE NEW 10,000-TON FRENCH CRUISERS.

crank shafts and the reverse gear shaft there are two vibration dampers of the fly-wheel type, the duty of which is to absorb crank shaft vibrations, and so protect the gear teeth. The auxiliaries include the usual lubricating oil and circulating water pumps, and arrangements are made whereby the engine can be started on compressed air, which is operated from the control pillar.—"The Engineer," September 28, 1928.

CHARACTERISTICS OF THE *COURAGEOUS* CHANGED BY REBUILDING.

Conversion and reconditioning have changed this obsolete 9½-knot freighter, and her two sister ships, *Triumph* and *Defiance*, into modern 13-knot Diesel-electric craft that set a new and higher standard for American freight vessels.

Whether in agreement or not with the bold step of lengthening and converting the *Courageous*, *Triumph* and *Defiance* to a form of propulsion hitherto untried with cargo vessels of their large size, shipowners must necessarily watch the service performances very closely. For these vessels may—and very probably will—have a tremendous influence on freighter construction, just as the Atlantic Refining Co.'s Diesel-electric tankers may effect bulk-oil carrier design. The tendency today is for higher powers and higher speeds, supplanting full-lined slow freighters with bigger and faster cargo-liners capable of running on time table schedules and capable of carrying a limited number of passengers. This the Diesel engine, with its economical fuel consumption and consequently small bunker need, has made possible and practical.

The conception of Diesel-electric drive, with its smaller, faster-running power units in conjunction with even slower propeller speeds than heretofore, for one thing renders feasible higher powers and higher ship speeds, without materially increasing standard Diesel engine sizes. Thus larger cylinders and other parts are avoided. Far-seeing naval architects can readily grasp the fact that the 15-knot and 16-knot cargo-liner is very, very close at hand.

Had the *Courageous* and her sisters been specially designed and built, the advance in shipbuilding would have bordered on radical, so great would have been the change. But in this Supplement we will confine ourselves to the facts. Congress would not permit new construction. Such material as was available had to be taken by the Board and moulded into shape, *i.e.*, by remodeling and repowering existing obsolete steam ships that had been built for smaller powers and lower speeds and with the ruthless disregard of fair lines so noticeably absent from much of the war-built tonnage.

While still a Commissioner of the Shipping Board, Admiral Wm. S. Benson had the vision to see the merits of the Diesel-electric conversion plan which he proposed and had the courage to force the proposal into definite action in the face of caustic criticism and strong opposition from many influential quarters.

In the *Courageous* we now have a ship that can maintain over 13 knots—not a fast ship in these days of cargo motorliners, but nevertheless very much faster than the 9½ knots her original design gave her. She can handle loading and discharging cargo at a very much higher rate than before on a greatly reduced fuel consumption, so is far more efficient in port. Her hull and Isherwood framing are in excellent shape. Her engine foundations are considerably stronger and heavier than before. So she is good for at least fifteen years of service. Before conversion she was useless and inactive, and would have remained so until scrapped. It cost about a million

and a quarter dollars to convert her. It would have cost an additional three hundred thousand dollars for a new ship. As the Administration and Congress would not permit of the latter, it is of no use to say that a new ship would have been far more efficient. Besides, everyone knows that, and a new ship would still leave the Board with an obsolete hulk that nobody wanted. Under these circumstances, the conversion is justified. Results in service are calculated to support this belief. These remarks also apply to the *Defiance* and *Triumph*.

Before proceeding further let us quote the general dimensions, power, etc., of the *Courageous*, before and after conversion, at the yard of the Federal Shipbuilding and Dry Dock Company, Kearny, N. J. The changes must be studied in the light of the particular conditions of the trade in which she will operate, viz., North-Atlantic—Philippines—S. China.

GENERAL SPECIFICATIONS "COURAGEOUS."

1. For the practical interpretation, as distinct from the academic interpretation, of the comparison below, the following points must be understood:

2. *Courageous* is capable of carrying substantially the same amount of cargo in the Eastern trade now as before her conversion, notwithstanding the increase of sea speed from 9½ knots to 13 knots.

3. Bale capacity and the bunkering practice in the Atlantic division of the American Pioneer Line annul the "apparent" disadvantage of the reduced net cargo capacity shown for the fully bunkered condition.

4. These conditions were taken into account in the proposal to lengthen the vessel, a procedure entailing increase of freeboard and therefore decrease of load draft. Reduced draft after conversion should be noted when looking at tonnage figures.

5. For trades in which weight cargo might be the rule, the conversion plans could be arranged to suit such conditions.

	Before Conversion	*After Conversion*
Length—overall	457 ft. 6 in.	468 ft. 6 in.
Length—between perpendiculars	440 ft. 1½ in.	457 ft. 4½ in.
Breadth—moulded	56 ft. 0 in.	56 ft. 0 in.
Depth—moulded	38 ft. 0 in.	38 ft. 0 in.
Draft—loaded summer	28 ft. 7½ in.	27 ft. 4 in.
Displacement (loaded)	15,946 tons	15,140 tons
Displacement (light)	4,078 tons	4,640 tons
Cargo Capacity (grain in holds)	577,992 cu.ft.	577,992 cu.ft.
Cargo Capacity (bales)	579,602 cu.ft.	576,765 cu.ft.
Net cargo capacity (with fully bunkered condition)	9,400 tons	9,128 tons
Bunker capacity (including deep tank in steamer.	2,138 tons	1,159 tons
Fresh water capacity	235 tons	213 tons
Dead-weight capacity (including fuel, water and stores)	11,773 tons	10,500 tons
Machinery weight (including aux. propeller and shafting)	.....	928 tons

	Before Conversion	*After Conversion*
Power (main engines)	2,645 S.H.P.	4000 S.H.P.
Type of machinery	Geared turbines and Scotch boilers	Diesel-electric
Daily fuel-consumption (main and aux. engines at sea)	35 tons	21 tons
Length of passage on full bunkers	13,900 sea miles	17,270 sea miles
Daily fuel-consumption (in port)	14 tons	3 tons
Donkey boiler consumption (at sea in winter)	nil	1 ton
Sea speed	9½ knots	13 knots
Propeller speed	80 R.P.M.	60 R.P.M.
Make of engines	General Electric	McIntosh & Seymour
Make of electric equipment	.....	General Electric
Length of machinery space	65 ft. 0 in.	65 ft. 0 in.
Length of main Diesel engines	.....	32 ft. 0 in.
Weight of each main engine	.....	60 tons
No. of men in engine and boiler rooms	17	12

RELATIVE TRANSPORTATION CAPACITY.

M. S. Courageous	*At Sea*	*In Port*	*Year's Mileage*	*Performance*
Before conversion	210 days †	155 days †	48,000 miles	100 per cent
After conversion	189 days	176 days	59,100 miles	123 per cent

Careful analysis of the comparative figures reveals many things not visible on the surface. In the first place, the speed has been increased by 3½ knots, or to 312 nautical miles from 288 per day. This has not been accomplished with an increase of fuel, but actually with a daily saving of 14 tons per day of oil at sea. The lubricating oil consumption will be increased by about 10 gallons per day, but this cost is more than offset by the big reduction of fuel in port, especially in summer or in warm climates. This port fuel saving will be about 11 tons of fuel per day. Despite the higher power and faster speed, the number of the engine-room crew has been reduced from 17 to 12—a saving of five men.

When the cargo is of a heavy nature, the *Courageous* will be able to handle a greater net load on a long run at full draft because she can cruise over 17,000 miles at 13 knots on her bunker capacity of 1159 tons, whereas the 837 tons deep-tank capacity would have had to be used before, and so encroaching on her net-cargo load. As a motorship, the deep-tank can be turned over to 28,635 cubic feet of cargo. Besides, there no longer is need for a large quantity of fresh water for boilers. The small quantity now carried does not interfere with dead-weight cargo. These things, of course, depend largely upon the nature of the cargo and the distance of the voyage. Fuel costs will depend upon what grade of fuel is selected by the Board or

† Assumed basis for comparison.

operators. As she has oil centrifuges, she should have no trouble in running on a mixture of Diesel oil and boiler-oil, or on the latter if circumstances demand it. The dominant point is that she now makes a much higher speed on a smaller fuel bill, while her earning power over a ten-year period is very much higher by reason of the greater number of voyages now possible.

The propelling machinery is located amidships in the space that was occupied by the old steam machinery. It consists of one double-armature propelling motor, four Diesel-generator units with attached exciters, two ventilating fans for the electric propulsion equipment, and one main switchboard. There are one auxiliary Diesel-generator unit, one auxiliary switchboard, and the usual engine-room auxiliaries. All the pumps are motor driven except the donkey-boiler feed pump, which is steam driven. All the electrical main propulsion equipment and the motors for the auxiliary machinery were supplied by the General Electric Company.

Of the double armature type the main propulsion motor is totally enclosed and forced ventilated. It has a normal output of 4000 S.H.P. at 60 R.P.M., and is capable of delivering a maximum of 4500 S.H.P. Each armature operates with direct current at 750 volts. The motor can be controlled either from the pilot-house or from the engine-room through the Ward Leonard system of control. A 41½-inch two-shoe thrust bearing is located abaft the main motor in a separate casting.

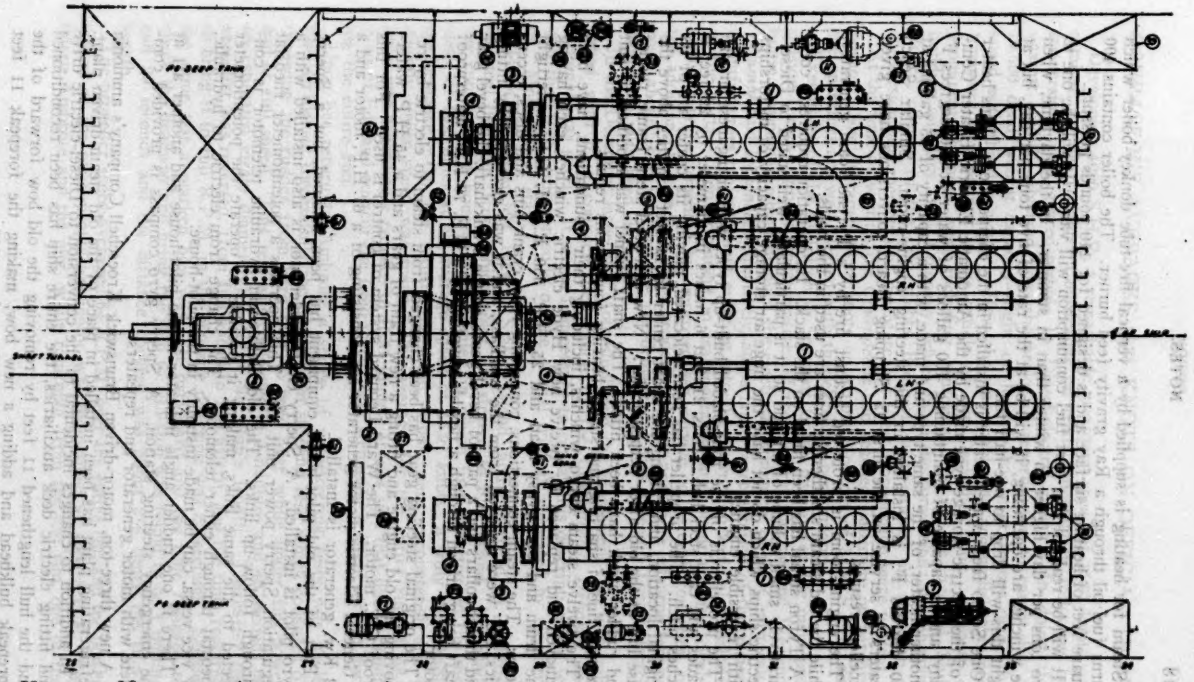
The four main Diesel engines were supplied by the McIntosh & Seymour Corporation. They are of the four-cycle, single-acting, air-injection, trunk-piston type. Each engine has eight cylinders, 20-inch diameter by 24-inch stroke, developing 1200 B.H.P. normal and 1320 B.H.P. maximum, at 250 R.P.M. Starting air for these engines is stored in four flasks at 1000 pounds per square inch. These flasks are connected directly to the engines through reducing valves which reduce the pressure to 400 pounds per square inch.

Each engine drives one 800 Kw. generator and 100 Kw. exciter. Generators and exciters are of the totally enclosed, forced ventilated type. Direct current is supplied by the generators at 375 volts, and by the exciters at 240 volts.

The two ventilating fans are located above the engine-room at the bridge deck level. They are of the multivane, double-inlet type manufactured by the B. F. Sturtevant Company. Each fan has a capacity of 35,000 cubic feet per minute and is driven by a 58 H.P. G. E. motor. The fans supply air to the propulsion motor, the generators, the exciters and the switchboard. The outlets from the main motor and generators are led into a common duct which discharges to the atmosphere above the fidley top. There are also four outlets to the engine-room. Numerous dampers and deflectors provide means of adjustment to insure correct distribution of air to the various parts of the system.

The engine-room pumps were supplied by the Worthington Pump and Machinery Corporation, and the motors by the General Electric Company. The lubricating oil and circulating water pumps are connected to common motors. Three sets are used in normal service, the other set being a stand-by. Seven pumps are of the centrifugal type and seven are rotary; one is a plunger pump and one is steam driven.

Electric current for port use—when the winches are not in operation—is supplied by a small Diesel-generator set consisting of a Fairbanks Morse two-cycle, airless-injection engine, direct connected to a 36 Kw. generator. It operates at 800 R.P.M., and supplies current at 240 volts. The auxiliary power system and the lighting system, throughout the ship, operates on 230 volt direct current.



How the Machinery Arrangements Admitted the New Installation Without Major Structural Alterations to the Engine-Room Space Is Shown by this Plan View.

Steam for heating is supplied by a vertical fire-tube donkey-boiler which burns fuel oil through a Ray gravity feed burner. The boiler contains 400 square feet of heating surface and is designed for 110 pounds pressure.

It will be realized that port fuel consumption will vary. It will be one to two tons per day higher in winter than in summer. In the daytime, when the winches are operating, it will be at the rate of five tons per day, but at night this will drop to one-half ton.

One Sepco fresh-water heater is installed in the engine-room. This heater is of the electric-storage type made by the Automatic Electric Heater Company, and is capable of maintaining 100 gallons of water at 160 degrees F. Another heater, of the same type and made, with a capacity of 15 gallons at 160 degrees F., is installed in the steering engine-room. Similar Sepco heaters in service on the first 12 Shipping Board conversions have given excellent results.

The engine-room is protected against fire by a Pyrene foam generator, while the old steam smothering lines are used in the holds.

A Tyfon signal has been fitted on the stack. Its operation requires a comparatively small volume of air and so it is particularly well suited to Diesel-electric ships which do not have the huge air storage capacity of motorships with reversible engines.

The propeller is of the four-bladed built-up type, with manganese bronze blades and cast steel hub. It is 21 feet 6 inches in diameter by 22 feet 9 inches pitch. The propeller has been relocated, moving its center aft of its original location, and raising the shaft center to 11 feet 3 inches above the base line at the old after perpendicular. New cast-steel stern frame, rudder and rudder stock have been fitted. The shaft tunnel was modified to suit the new line of shafting and steady bearing foundations rebuilt.

The twelve steam cargo winches, including their foundations, have been removed and replaced by twelve new Hyde electric winches, each having one drum and one gypsy head and 25 H.P. 550 R.P.M. G.E. watertight motor. The steam connections, connecting-rods, crank-pins and discs, eccentrics, etc., were removed from the windlass, and it was electrified by fitting end thrust collars and a pair of bevel gears on the crankshaft, the bevel gear shaft being driven through a fiexible coupling by a G.E. 70 H.P. waterproof motor.

The original steering gear has been changed from steam to electric by removing the old engine and fitting a new train of gears and a 45 H.P. waterproof G.E. motor. The Ward Leonard system of control is used. For this a General Electric motor-generator set, consisting of a 67 H.P. motor and a 43 Kw. generator is installed.

Part of the old pilot-house equipment has been retained, but a Sperry gyro pilot is installed. A Sperry electric telemotor is also installed with a regulation Sperry power unit aft. This operates a potentiometer rheostat through follow-up links. The old Bethlehem hydraulic telemotor is connected to the same links, making it possible to operate the potentiometer rheostat through either telemoter. The change from electric to hydraulic, or vice versa, can be made instantly in the pilot-house.

There is one rudder angle indicator in the pilot-house and another aft at the emergency steering station. A Sperry gyro compass is provided complete with motor generator and repeaters.

A new three-ton, motor-driven Brunswick Kroeschell Company's ammonia refrigerating plant has been installed in place of the old steam-driven plant.

In addition to changes incidental to the conversion to Diesel-electric drive and fitting electric deck auxiliaries, the entire ship has been reconditioned and the hull lengthened 11 feet by removing the old bow forward of the forepeak bulkhead and adding a new bow, making the forepeak 11 feet longer than originally.—"Motorship," December, 1928.

COURAGEOUS AVERAGES 15.31 KNOTS ON OFFICIAL TRIAL.

Developing 4000 S.H.P., a remarkable maximum speed of 15.97 knots was attained by the freighter *Courageous* on trials immediately following her conversion from geared-turbine to Diesel-electric power. In doing this against slightly adversed tides she broke all records, for no cargo ship of 10,500 dead weight capacity—light or loaded—has ever before made this speed with this low power. How she was enabled to accomplish this performance is explained in the article of our December issue. A party of prominent shipping men, including representatives of the Federal Shipbuilding and Dry Dock Company, which made the conversion; the Shipping Board, owners of the ship; Gibbs Brothers, who worked out the plan of conversion, and members of the Merchant Fleet Corporation were present.

At the time of writing the *Courageous* had reached Baltimore on her first voyage. She averaged 14.68 knots on a power output of 3400 S.H.P. and the operators are well pleased with this excellent performance.

Executives of the McIntosh & Seymour Corp., builders of the main propulsion Diesel engines; representatives of the General Electric and Westinghouse Companies, which supplied the electrical equipment of the *Courageous*, *Triumph* and *Defiance*, respectively, and a large representation of the various manufacturers of equipment entering into the conversion were also included in the party. Men prominent in transportation and manufacturing circles which may be benefited by improved sea service to foreign countries, by the addition of American ships rendering faster and more efficient service, were aboard and watched the performance of this splendid Diesel-electric motorship with keen interest.

In the December issue of "Motorship" and the supplement that was published with it, a complete description of the *Courageous*, *Defiance* and *Triumph* was given. It seems unnecessary to repeat this description and we will therefore outline results of the official trial as witnessed by members of "Motorship's" staff.

The *Courageous* left Pier 6, Staten Island, and proceeded to Ambrose Channel lightship, from which point she steered to Fire Island. She made the run out in 1 hour and 49 minutes, in which time she covered the distance of 29.2 miles at an average speed of 15.97 knots; a truly remarkable performance. On the return run head winds were encountered and a slightly lower speed was made. The average for the entire run of 58.4 miles was accordingly reduced to 15.31 knots. It was said that due to conditions of tide and current the *Courageous* was stemming a slight stream during the entire run.

Upon her return to Ambrose a series of maneuvering tests was made. She performed successfully the figure-eight steering test, which consisted of throwing the rudder from hard over to hard over while under full power and at full speed. This test was completed in 3 minutes and 40 seconds on an estimated circle diameter 3½ times the ship's length. Thereafter the propeller was reversed, from full ahead to full astern, and the time required to bring it to full R.P.M. in the opposite direction was 22 seconds. During the same test a marked box was cast overboard and the time required to check the headway and bring the ship to full-stop was found to be 1 minute and 29 seconds and the distance covered was about 2½ times the ship's length.

The propeller speed averaged 64 R.P.M. over the entire run and the power output of the main propulsion motor was maintained at 4000 S.H.P. Between Ambrose and the pier, while returning from the test run, one of the

engines was shut down and the propeller speed came down to 58 R.P.M., only 6 revolutions less than with full power. Unfortunately, the distance was not great enough to obtain a check of the speed under three-quarter power.

The good performance was an agreeable surprise to everyone connected with the conversion and rather a shock to the skeptics. It is as good if not better than any performance that has been made by any ship under similar conditions and within her size class.

With a service speed of 14 knots in place of the estimated 13 knots, the *Courageous, Defiance* and *Triumph* will be far superior to their competitors in the round-the-world service of the Roosevelt Steamship Company, which will operate them for the Shipping Board.

The main propulsion machinery of the *Courageous* consists of four McIntosh & Seymour 1200 S.H.P. 8-cylinder Diesels, direct connected to General Electric generators, which operate at 250 R.P.M. and supply current to operate the 4000 S.H.P. G.E. main propulsion unit and to the auxiliary machinery. The *Courageous* has a length of 486 feet 6 inches, beam 56 feet, depth 38 feet, and draft of 27 feet 4 inches. Her estimated daily fuel consumption is 21 tons per day. She has a bunker capacity of 1159 tons and has a cruising radius of 17,250 sea miles on one filling of bunkers. The deadweight capacity is now 10,500 tons.

The trial trip was run by the regular operating crew, with Captain B. P. Taylor in command, with L. B. Adams, E. M. Sharpe and J. P. Anderson as chief, second and third officers, respectively. Chief Engineer J. Brown was in charge in the engine-room, with R. Myers, J. Bloosch, Jr., H. B. Berg and M. McDonald, first, second, third and fourth assistant, respectively.—"Motorship," January, 1929.

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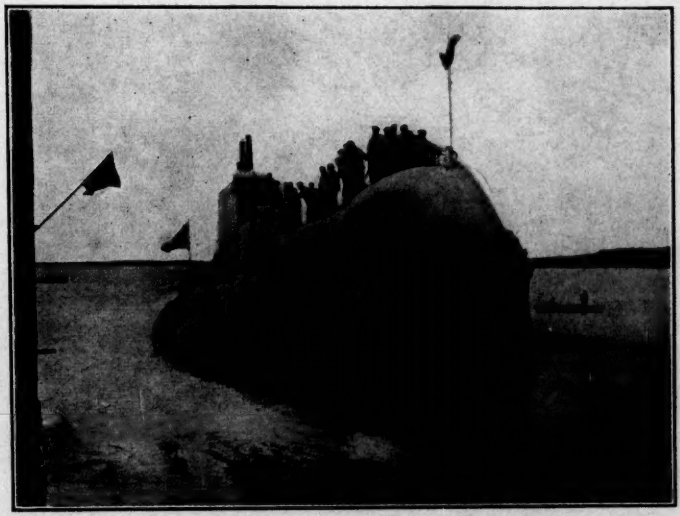
3. ENGINEERING ON SHORE.

HIGH-PRESSURE TURBO-ALTERNATOR SET.

The steam turbine illustrated herewith has been designed for the unusually high pressure of 725 pounds per square inch at 442 degrees C. It is of the three-section straight condensing type, and when running at 3000 R.P.M. will develop 20,000-25,000 Kw. The temperature drop in each cylinder is comparatively small; in the high-pressure section, for example, being only 150 degrees C. Owing to the high pressure of the live steam and its wetness in the low-pressure stages, certain special features have been introduced. The shaft *a* of the high-pressure section is rigidly coupled to the shaft *b* of the intermediate-pressure section, whilst the latter is connected to shaft *c* of the low-pressure element by means of a claw-type flexible coupling. From a fixed point *d* between the high-pressure and intermediate-pressure sections, at which a thrust bearing is located, the shafts and cylinder casings are free to expand in either direction. The rings *e*, which constitute the rotor drums of both the high-pressure and intermediate-pressure turbines, and which carry the reaction blading, are secured by means of the spring rings *f*.

The rotors of the high-pressure and intermediate-pressure portions are of similar construction, and each comprises three ring sections, as described above, although the last ring of the high-pressure portion is forged solid with the shaft. Their construction ensures that the material of each individual part is thoroughly sound, and that the rate of heating up of all the parts is as uniform as possible.

"Courageous" on Official Trial Shows Almost No Bow Wave, a Clean Wake, and a Clean Exhaust, All Indications of the Factory Results Attained.



Launch of the Chilean Submarine "Capitan O'Brien."
—"The Shipbuilder," Nov., 1928.

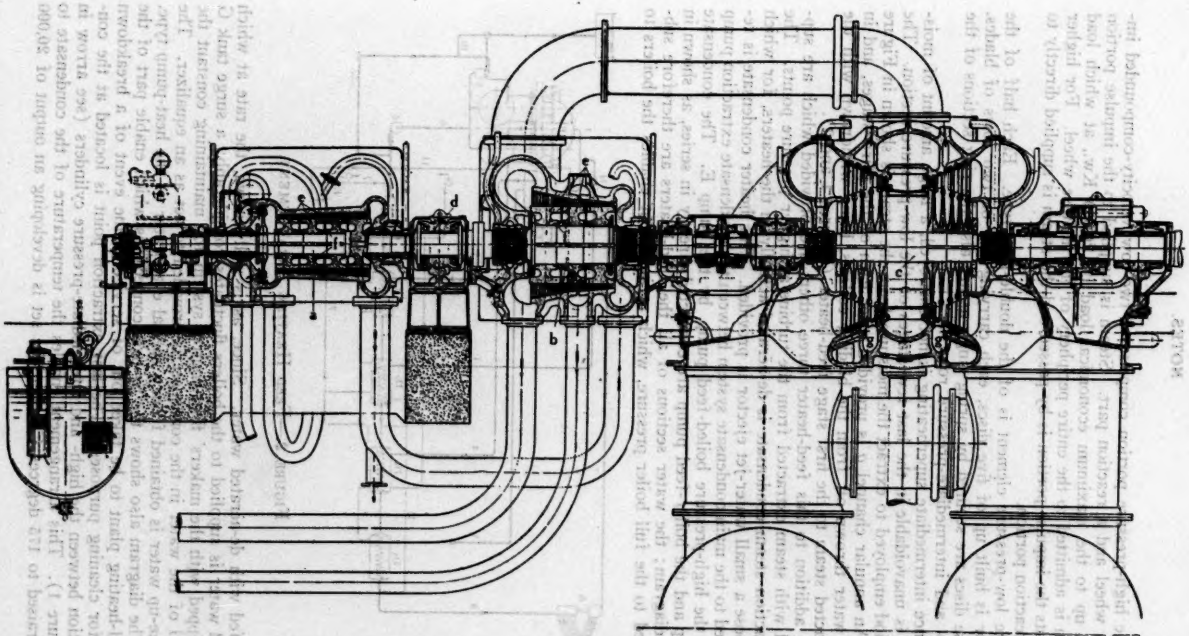


FIGURE 1.—SECTIONAL VIEW OF TURBINE.

The high-pressure portion comprises a two-row velocity-compounded impulse wheel and a reaction part. Steam is supplied to the impulse portion only, up to the maximum economical load of 20,000 Kw., at which load steam is admitted to the entire periphery of the impulse wheel. For higher outputs the impulse portion is by-passed and the steam is supplied directly to the reaction portion.

The low-pressure element is of the double-flow type. Each half of the motor is built up of five discs, each carrying one or two rows of blades. These discs are secured by spring rings, as are also the ring sections of the high- and intermediate-pressure rotors.

Since intermediate superheating is not employed, a large amount of moisture is unavoidable in the last few stages of the low-pressure section. The method employed to extract the moisture from the steam is shown in Figure 1. An annular channel *g* is provided after each of the third stages, and in this water thrown off from the blading collects, being withdrawn with the extracted steam to the first stage feed-heater (Figures 1 and 2).

In addition to this feed-heater three others are provided which are supplied with steam extracted from the turbine at higher pressure points. The extraction steam condensate is de-aërated actually in the heaters, for which purpose a small water-jet ejector is provided. This heater condensate is returned to the main condensate system between the condensate extraction pump and the high-pressure boiled-feed pump, by the pump E. The condensate pump and the boiler-feed pump are connected directly in series, as shown in the diagram; the water sections of all the feed-heaters are therefore subjected to the full boiler pressure, which arrangement enables the boilers to

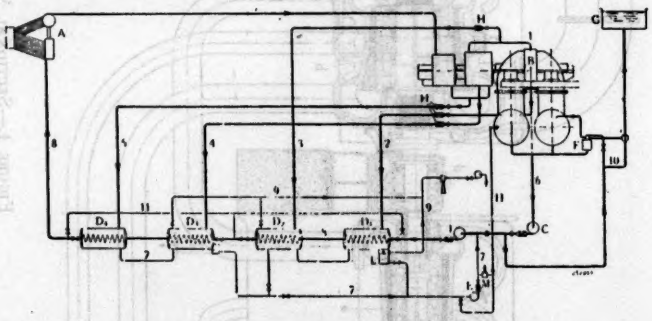


FIGURE 2.—FEED HEATING ARRANGEMENT.

be fed with de-aërated water. Since, as is well known, the rate at which feed water is supplied to the boilers fluctuates considerably, a surge tank G equipped with the makers' float-control system for maintaining constant the level of the water in the condenser is provided to act as an equalizer. The make-up water is obtained from a special evaporator of the heat-pump type.

The diagram also shows the by-pass connections which enable part of the feed-heating plant to be taken out of service in the event of a breakdown or for cleaning purposes. The last extraction point is located at the connection between the high- and intermediate-pressure cylinders (see arrow in Figure 1). This arrangement enables the temperature of the condensate to be raised to 175 degrees C. when the set is developing an output of 20,000

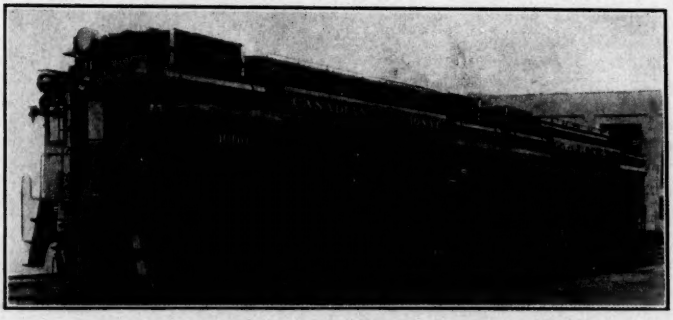


FIGURE 1.

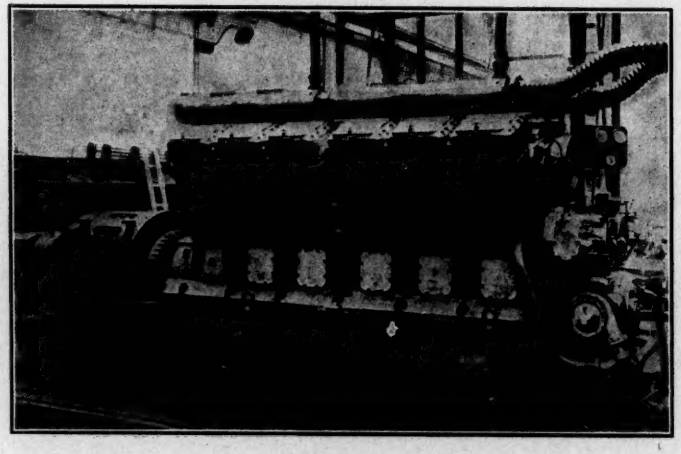


FIGURE 2.

Kw. at the alternator terminals, the resulting heat economy amounting to 8.4 per cent. An over-all efficiency for the plant of about 27 per cent is expected to be realized.

The turbine drives an alternator which at a power-factor of 0.8 can develop a continuous output of 25,000 Kw. at 12,000 volts. As the set has an over-all length of approximately 49 feet and has to be erected in the existing engine-room, which is 60 feet wide, the exciter and the ventilating fan for circulating the cooling air through the generator are mounted in the basement and driven by an electric motor, or in the case of emergency by a small steam turbine.

The turbine is being constructed by Brown, Boveri and Co., Limited, Baden, to which firm's "Review" we are indebted for the illustrations and particulars given.—"Mechanical World and Engineering Record," December 21, 1928.

2660-H.P. OIL-ELECTRIC LOCOMOTIVE FOR THE CANADIAN NATIONAL RAILWAYS.

It has been known for some time that Messrs. William Beardmore and Company, Limited, of Glasgow, have had under construction two large oil engines for an oil-electric locomotive for the Canadian National Railways. This design of locomotive has followed on the success achieved by the Beardmore oil-electric cars, the first of which was put into commission on the Canadian National Railways about three years ago. We give an illustration of the new locomotive in Figure 1, and of one of the Beardmore engines with which it is fitted in Figure 2. The locomotive is now running between Brockville and Belleville, Ontario.

The machine consists of two units, weighing together 290 tons, of which 214 tons are available for adhesion. Each unit has one 12-cylinder engine of the type illustrated, and a generator supplying current to four driving motors geared to the axles. The gear ratio has been chosen for high-speed passenger service and gives a tractive effort of 100,000 pounds during acceleration, and 42,000 pounds continuously. The electrical equipment has been designed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, and was supplied by the Canadian Westinghouse Company, of Hamilton, Ontario. The mechanical design is the result of collaboration on the part of the Canadian National Railways, the Canadian Locomotive Company, and the Baldwin Locomotive Works. The main frames are steel castings supplied by the Commonwealth Steel Company, and the four-wheel and two-wheel truck frames and other parts were also supplied by this firm.

The two main engine units each consist of twelve cylinders of 12-inch bore and 12-inch stroke, running normally at 800 R.P.M. The engine has airless injection, and the control enables it to be run at any speed from 300 to 800 R.P.M. The engine develops its rated horsepower at a consumption of 0.43 pounds per brake horsepower-hour. It is started up by battery supply, the main generator being used to turn it over. Water cooling is arranged with radiators on the roof. The lubrication system is also provided with coolers. In addition to natural air cooling, which will suffice in cold weather, supplementary fan ventilation has been provided for use at other times. The engine exhaust is carried to an exhaust boiler of the thimble tube type, supplied by Messrs. Clarkson Steam Motors Company, Limited, London, which also furnished a separate auxiliary oil-fired boiler of the same type. These boilers, which are fitted with automatic water-level control, supply steam for heating. When there is no demand for steam, the exhaust boiler on the engine operates dry, as a silencer, and the auxiliary boiler is cut out.

The main control system provides for varying the speed of the main engine, the generator voltage and shunting the field of the series type traction motors. Torque governor control ensures continuous air supply and battery charging conditions, regardless of engine speed. A motor-driven blower in each cab supplies forced ventilation to the traction motors when operating under freight conditions.

The driving journals and two-wheel truck journals are fitted with waste-packed boxes, but the four-wheel truck journals, of the outside type, have floating bushes and are grease lubricated. Each unit carries 8000 pounds of fuel oil, 11,000 pounds of boiler water, and 3000 pounds jacket water, the fuel being sufficient for 12 hours' operation. With the present gear ratio, though primarily intended for high-speed passenger work, the locomotive will handle on a 0.4 per cent grade a train of 2800 tons at 19 M.P.H., or 40 M.P.H. on the level. If a ratio of 18:73 were adopted specially for freight work, the capacity would be 3700 tons on a 0.4 per cent grade at 15 M.P.H., or 35 M.P.H. on the level. Provision is made for fitting both engines with superchargers, which would result in a considerable increase in power.—"Engineering," December 14, 1928.

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4. ENGINEERING MATERIALS AND PROCESSES.

CARBOLOY—A NEW TOOL MATERIAL.

By Dr. Samuel L. Hoyt

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.

The great hardness of tungsten carbide has been known for a long time, and many attempts have been made to take advantage of it commercially. Tungsten carbide, however, as commonly manufactured, is too weak and porous for those industrial applications in which its high cost would permit it to compete with other hard materials. This circumstance accounts for the efforts which have been made, both here and abroad, to eliminate or control the porosity and to increase the strength of tungsten carbide. Obviously, this strengthening must not be obtained at too great a sacrifice in hardness.

German investigators have been particularly active in this field, as shown by the various patents covering tungsten carbide. One of their important developments, a contribution from the incandescent lamp industry, is the tungsten carbide and cobalt combination represented by the "Hartmetall" of the Osram Company. By means of cobalt, tungsten carbide is made about half as strong as high-speed steel, while still retaining sapphire scratching hardness. In the writer's opinion, great credit is due the inventors of this carbide tool material. A super-hard carbide tool material of this type, which has somewhat unusual properties, has now been developed in the Research Laboratory.

These carbide tool materials seem destined to play a dominant part in the industrial life of the future, and, on that account, the Research Laboratory has actively pursued the study of them for the past few years. This work was initiated, by the writer, in the Research Laboratory, but it has since been greatly extended in the Company's shops as a large-scale investigation. Various forms of carbide tool materials have been studied and it is the experience thus gained which will be described here. The name Carboloy has been adopted as the trade name for materials of this type.

CHARACTERISTICS OF CARBOLOY.

The density of Carboloy is about 14 grams per cubic centimeter and upward, depending on the amount of cobalt used. This characterizes it as a heavy metal, almost of the tungsten class. It does not tarnish and, when ground, resembles steel in appearance. It resists chemical attack remarkably well and is a pleasing and satisfactory material for use in the arts.

The hardness of such materials can be specified in a number of ways. Sapphire is the mineral which comes next below the diamond in hardness. Carboloy is capable of producing a well-defined scratch in the natural sapphire. When it is borne in mind that the sapphire has an "absolute hardness" of 1150 kilograms per square millimeter, and that a mineral which is as hard as feldspar has an "absolute hardness" of only 300, the hardness of Carboloy receives new significance.

A sample of Carboloy ground to an edge of about 90 degrees is capable of cutting a rather deep, narrow groove in an Alundum wheel without suffering much loss itself; whereas our ordinary tool materials are worn away by an Alundum wheel. This behavior on the Alundum wheel gives a very good idea of the hardness of the material; even the manner in which a sample scratches a plate of glass serves as a crude test. However, a quantitative, or at least a numerical, expression of the hardness is much more illuminating, as is given by the more formal methods of testing hardness.

Engineers will be more interested in the Brinell or Rockwell tests; and, in our work, we have used the Rockwell test almost exclusively to get the correct evaluation of the hardness. Obviously, it is not possible to secure the Brinell number in the usual way. For the sake of obtaining quantitative values of the hardness of our samples, and for comparing different materials and treatments, we find the actual unit load supported by the sample during the Rockwell test. This gives a load in kilograms per square millimeter, and it is so closely like the Brinell number in the higher ranges (within 100 to 200 points) that its designation as such seems justified.

In the earlier tests we used the 150-kilogram load with the diamond penetrator and recorded hardness numbers of around 70 on the "C" scale. This load caused the point of the diamond to wear and crumble in too short a time, and we have since changed to the "no load" scale, which simply means that no weight is put on the lever arm. The hardness numbers are read on the "C" scale and have come to be known as the Rockwell "A" numbers. To get the unit load on the sample, it was necessary to measure the actual load for the "no load" loading. By making impressions in a sample of hard steel with 150 and 100 kilograms and with "no load" and then measuring the three impression diameters with an accurate comparator, this load was found to be 64 kilograms for our machine by utilizing the principles of Meyer's analysis. The load for our modified test, having been determined, it is then possible to calculate the unit loads for different Rockwell "C" scale readings, or Rockwell "A" numbers.

This can be done by the relationship given in Figure 1. It is not likely that the designation of hardness numbers secured in this way as Brinell numbers will be misleading; and their use brings out differences in hardness much better than the Rockwell numbers do. Certainly, nobody accustomed to measuring penetration hardness will be misled thereby. In practice we measure the "no load" Rockwell hardness on the "C" scale and use the numbers so obtained without converting them into Brinell numbers. The "A" readings obtained on one sample do not differ by much more than $\pm$ 0.5, while the readings of different diamonds may differ from each other by a little more than this as an average maximum.

We may now compare the penetration hardness of different materials on a rational basis. O'Neil has shown that the Brinell number of the hardest steel may be taken as about 1000, using a diamond ball point as the penetrator. Common hardened tool steel probably runs closer to 850 as a maximum. The Brinell number of the original German material runs from 1250 to 1400, so that it represents a considerable increase over the hardest steel, while the newer grade runs from 2000 to 2500. The Rockwell "A" numbers for these two materials run 85 to 87 for the former and 90.0 to 91.5 for the latter. An interesting check on the relative hardness is secured by comparing the size of the two impressions made, even with the unaided eye. To those who might wish to know the ordinary Rockwell "C" number, the only informa-

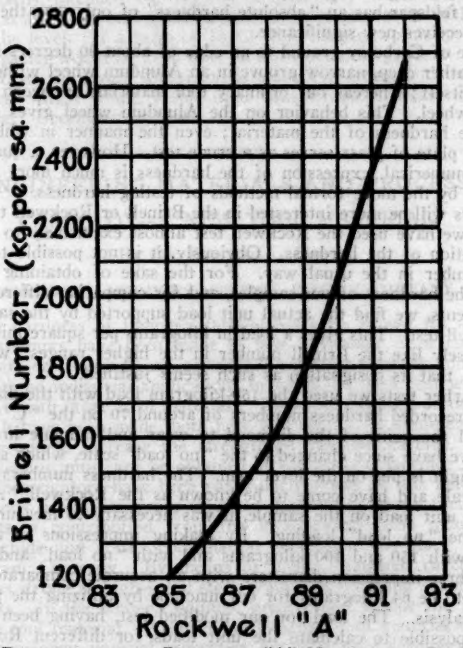

FIGURE 1.—RELATIONSHIP OF ROCKWELL "A" NUMBERS TO BRINELL HARDNESS NUMBERS.

tion that can be given at present is that the original German material runs around 70, while the super-hard material has been found in a few trials to run 75 and above. The wear and tear on diamond points is too great for testing with the 150-kilogram load, but, of course, the sensitivity is reduced by going to the "no load" reading.

Inasmuch as the strengthening of tungsten carbide has been the feature which has given these materials promise of industrial use, this property has more than common interest. D'Arcambal has shown that quenched and tem-

pered high-speed steel has a modulus of rupture in a transverse or cross-bending test of around 425,000 pounds per square inch. Similar tests have been run on the new tungsten carbide tool materials at the Research Laboratory, using a section one-quarter of an inch square with supports one inch and a half apart. The German material is found to run around 225,000, and the super-hard material around 250,000 to 275,000 pounds per square inch. We have not found it feasible to get a figure for the pure carbide (*i.e.*, without the cobalt), to compare with these figures. It is not likely that a good figure could be obtained, but we may safely say that the pure carbide would come under 50,000. Our experience indicates that such a material would be very weak.

These figures show that tungsten carbide has had its strength increased to somewhat over half that of high-speed steel. Viewed in one light, this is to be considered as a very substantial achievement, but this strength must also be regarded as a factor which places a definite limitation on the use of tungsten carbide in commercial practice.

Another important property of a material of this type may be called "toughness," the ability of a material to stand up under stresses or impacts imposed on relatively small areas. A weak, or fragile, material would chip and flake off, but a tough one would be able to stand stresses of this type without injury. The new carbide tool materials possess their share of toughness, since they withstand quite severe blows, or sufficient to indent a supporting block of copper. Inasmuch as the break comes abruptly when the bar does break, the material is brittle, in that sense. The fracture is of the curved type, while a weaker, or less "tough," material would break straight across. A further demonstration of strength and toughness is afforded by the use of Carboloy on intermittent cuts on metals.

The thermal expansion and thermal conductivity of Carboloy are low, but quantitative data will not be given at this time.

The chemical stability of a new material is naturally of considerable interest. Carboloy is probably permanently stable at room temperature and under normal conditions, for we have observed no deterioration in several years. It does not pit or tarnish, and is dissolved in acids only with great difficulty. In many respects it may be expected to show somewhat similar properties and behavior to tungsten. At elevated temperatures the carbide oxidizes, as other tungsten products do when heated in an oxidizing atmosphere. On this account the various operations which are performed on Carboloy at high temperatures are carried out under non-oxidizing conditions. The moderate temperatures involved in cutting metals at the speeds which we generally use have not been observed to be harmful. If the speed is raised too high and the abrasion is severe, small particles of carbide may oxidize and shoot off the edge as sparks. Ordinarily, the temperatures involved simply produce temper colors, much the same as they do on high-speed steel.

Finally, we have to consider the way in which Carboloy retains its strength and hardness at elevated temperatures. No quantitative test data can be given at this time, but we know from the performance that Carboloy retains its hardness at a bright red heat to a most remarkable degree. Tools have been observed cutting nickel steel when the point is at this temperature and quite without ill effects.

That such strength, hardness, toughness, and chemical stability just cited, plus the ability to take and keep a cutting edge, must characterize a material of most extraordinary possibilities, as compared to our present tool materials, is self-evident to all who are conversant with this field. But we have found

that the performance of Carboloy on the lathe and in the shop does actually exceed the predictions which one might make from a knowledge of these properties. This, in turn, is doubtless due to two circumstances which are highly favorable to Carboloy. Carboloy has no "temper" to be "drawn" by the heat generated, and it is actually much harder than the materials machined, even at elevated temperatures, while steel tools are frequently softer. To get a better understanding of the performance of Carboloy tools, let us turn to a review of our experience in several exemplary fields.

One's first experience with a material having such remarkable properties is apt to mislead him into believing that it is capable of almost anything; but Carboloy, like other materials, has its breakdown point, first, through deficiency in one property, and then in another. Early in the work it became of interest to determine this breakdown point as one means of estimating the economic value of the tools, and, particularly, to compare it in this respect to the tool materials with which it would have to compete. In this way we have been led to try Carboloy tools on jobs which are not at all "commercial" and have secured some very valuable information. In this light it may not be amiss to review some of these experiences.

TESTS.

Glass proved to be quite easy to machine, or to cut with screw threads; and we soon found that hard porcelain insulators could be machined on a shaper. It is not often that one wishes to machine anything like hard porcelain; but since discovering that we could do so, we have found that these tools have been used for such work to a limited extent. Hadfield's manganese steel has always belonged to the non-machinable class; but it was found to yield easily to Carboloy, so easily, in fact, that it would seem that the operation could be developed commercially. For a check on the Carboloy test, a similar test was run with a standard steel tool on the same material, and it was found that the steel tool lost its edge almost at once, as was to be expected. Since then we have found Carboloy tools to be of great assistance in handling many of these hard, tough, and non-machinable steels. At the Research Laboratory we have occasion to prepare and test many different alloy compositions, and frequently find that it is only with the new tools that such alloys can be shaped or surfaced. This experience suggests that steels with higher alloy contents than are now commercially machinable will some day be brought into the machinable class. So far this work has consisted simply in doing jobs which could not ordinarily be done.

At one time we attempted to machine a block of quenched high-speed steel on the shaper. This attempt appeared to be the height of folly, but at least we satisfied our curiosity as to our ability to take a cut on such a hard, tough material; in that we were successful, but the tool performance was not at all satisfactory, for the edge crumbled. The same was found to be the case on several attempts to machine tool materials of the cobalt-chromium alloy type. If one were obliged to machine these alloys, he would be fortunate if he had tools of the tungsten carbide type at hand; but the grief involved, in tool breakage, would be uncommonly great for ordinary machine shop practice.

A complete knowledge of the essential properties of Carboloy and a correct understanding of the requirements of a particular service would enable us to predict the behavior of Carboloy in that service. Of course, our knowledge is not so complete, but we probably do know enough to enable us to select the most promising fields. Thus we should expect the peculiar virtues

FIGURE 2.—CUTTING GLASS ON A LATHE WITH CARBOLOY—START OF CUT.

FIGURE 3.—WIDE AND DEEP GROOVE IN GLASS, CUT WITH CARBOLOY.

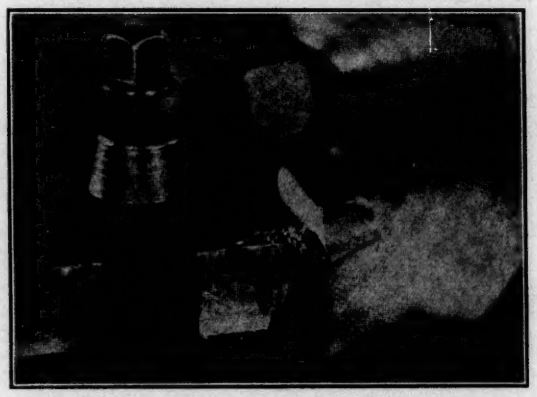

FIGURE 4.—CUTTING A HIGH-SPEED STEEL CUTTER IN A LATHE WITH CARBOLOY.

FIGURE 5.—USING THE CARBOLOY CONCRETE DRILL.

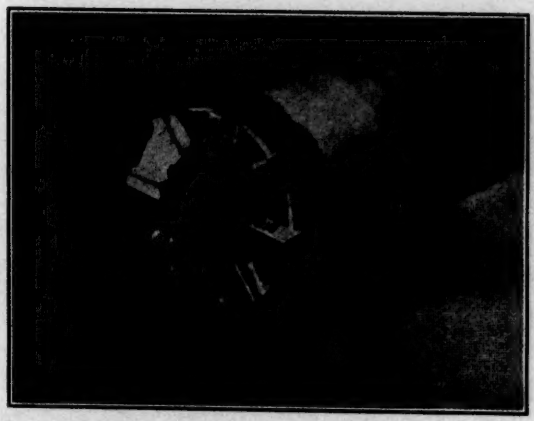

FIGURE 6.—TIP OF CARBOLOY DRILL FOR DRILLING CONCRETE.

FIGURE 7.—TIP OF CARBOLOY DRILL, SHOWING CORE OF CONCRETE.

FIGURE 8.—TESTING THE CARBOLOY CUTTER ON A NICKEL-STEEL TEST LOG, SHOWING LONG TURNING COMING FROM LOG. THE USUAL HIGH-SPEED CUTTER IS QUICKLY DULLED ON THIS TEST.

FIGURE 9.—COMPARISON OF HIGH-SPEED STEEL AND CARBOLOY CUTTERS AFTER USE ON NICKEL-STEEL LOG. THE STEEL CUTTER (LOWER) IS BURNED; THE CARBOLOY CUTTER (UPPER) HAS NOT BEEN AFFECTED.

of Carboloy to be most prominent in the field of weak or low-tensile materials, which are also uncommonly abrasive to our present tools. Fortunately, for our experimental purposes, the electrical industry furnishes a goodly number of such materials which must be machined in daily production. Without attempting to observe any particular order, our experience with a number of these will be given.

In the production of fused quartz, it has been found advantageous to use molds of carbon—the hard abrasive variety. A considerable amount of experimenting had shown that even the best tool steel lost its cutting edge and began cutting a taper soon after starting a cut on carbon. The grief involved in machining a hollow cylinder of carbon may be easily imagined. On putting Carboloy tools on this job we found at once that we could take the entire cut without tool wear, and therefore without tapering. This statement means, of course, that the cut was parallel within the tolerance allowed.

Genelite is composed of copper, tin, and carbon. It is so soft in one sense, that it can be whittled with a knife blade very easily, but it is also so abrasive that a lathe operation dulls a steel tool almost at once. A cut on a small cylinder of only a few inches in length is always on a taper. This again demonstrates the extreme abrasion which may be involved in the machining of carbon. Carboloy tools were found to machine Genelite with no difficulty and accurate tests of the cuts made showed that they were not tapered. A careful inspection of the cutting edge confirmed this observation by showing that no wear had occurred.

Commutators of electric motors are composed of alternate layers of copper and mica. The bearing surface of these has to be machined after assembly on the shaft. The mica is quite abrasive and has always presented a problem to the machine shop, for the operation is one which must be carried out very accurately. With high-speed steel a sacrifice must be made on this job, either in speed or in the finish of the surface; whereas the Carboloy tools cut through the mica without undue wear and give a smooth finish to the commutator.

Mycalex is an insulating material of such excellent properties that there is considerable demand for it in the electrical industry, in spite of the extreme difficulty with which it can be shaped or machined. It is composed of fine mica particles and lead borate, the latter acting as a bond for the mica. Ordinary tool materials are worn away at once on Micalex, so quickly that it would be difficult to give quantitative data on their performance. The effect and noise produced brings to one's mind a picture of an attempt to machine a grinding wheel. Carboloy tools, on the other hand, are capable of machining Mycalex commercially, and we have observed tools cutting over 1000 feet linearly, before losing their edge. Other molded compounds come under the same category and need not be considered separately.

Matrials like Bakelite and hard rubber are very abrasive when machined at high speeds. One of our operators showed me that even though he had made his steel tool as hard as "fire and water could make it," the cutting edge was rounded off very soon on hard rubber. Although the ease with which this machining was done made this result surprising, the evidence was very clear. Carboloy tools keep their cutting edge very well on hard rubber, and have been used with very satisfactory results.

Bakelite offers somewhat similar problems and, on account of the necessity of machining Bakelite at high speed, diamond tools have been commonly used. This was the only tool material which had been found to stand up at the speeds used, but the diamonds possessed one disadvantage which was overcome by substituting Carboloy. If the part machined contained a metal

insert, a special operation was required to recess this part below the cut of the diamond, for if the diamond hits the metal at high speed, it breaks off at once. Here the Carboloy tool necessitates no such special operation, for it cuts both Bakelite and metal insert.

On a somewhat similar operation we compared Carboloy tools with Stellite tools which had given the best performance on this operation up till then. Three tools were used on this job on two different heads, finishing three faces on the part. The Stellite tools required redressing every 150 parts machined, on the average, before the tools became dull enough to require sharpening. Carboloy tools were substituted under the same operating conditions, and finished 11,000 parts before they became dull enough to be redressed.

In the "low tensile" field the durability of Carboloy tools has been found to be of the order of 25 to 75 times that of high-speed tools, or so great that the simplest kind of a test demonstrates the vast superiority of the carbide tool. Here the tool pressure is always light, the cuts are small, and the cutting speeds are high. Resistance to either wear or "burning" is the chief requirement of the tool.

Coming to cast iron, we find that the cutting conditions are apt to be radically different. The parts are frequently large, the cutting speeds are much lower, the cuts are heavier, and the tool pressures are greater. The heavier pressures are due in part to the higher unit pressures exerted by the iron, but more particularly to the larger cuts. In this way the tool pressure becomes a more prominent factor in tool performance, but our experience shows that cast iron comes well within the field which can be handled by Carboloy.

The machining of cast iron by Carboloy offers a variety of problems, so that it will be well to consider the subject from several different points of view.

One of the most difficult jobs to do on cast iron with the usual tools is that of removing the surface layer, particularly if the surface contains sand. This is due to the fact that the chilled iron and sand are harder than the tool used to cut them. As has been pointed out, Carboloy is harder than sand and chilled iron, so that castings which would take the edge off high-speed steel almost at once can be handled with but little difficulty by Carboloy. In fact, we commonly use about the same speeds and feeds on these cuts that are used on the sub-surface cuts. Even cuts which travel in and out of the surface layer cause no particular trouble, and such cuts are recognized as being the most abrasive on the tool.

A somewhat similar problem is presented by "hard" castings. If a machine shop is accustomed to machining castings of some particular grade, a run of castings which is appreciably harder is certain to increase the machining costs whether the increase be due to annealing, to a lower production rate, or to scrapped castings and lost time. These castings may be, and quite likely are, of a better grade than the softer castings with which the shop is accustomed to deal. From that point of view it is unfortunate that they cannot be satisfactorily and economically handled. Carboloy tools machine these "hard" castings with ease, and it has been our experience that a run of such castings will go through the machine shop without disturbing the practice in any way. Naturally, the life of the tool is diminished according to the increased abrasion of the harder iron, but the tool life of Carboloy on cast iron is normally so great that the decrease involved is not a serious matter. Furthermore, it is not an uncommon occurrence that the use of Carboloy tools obviates the necessity of scrapping a large casting on which

a considerable amount of work has already been done. The cost of the casting may be many times as much as that of the tools used. The improvement in shop practice and morale can be easily pictured by those who have this type of work under their supervision.

In the manufacture of armature spiders for electric motors it is necessary to take a cut over the ribs to true up the spider. This cut is an intermittent one, and has given us an excellent opportunity to test the behavior of Carboloy tools under impact. The impact on the Carboloy tool is generally greater than on the high-speed tool on account of the higher speeds used with the former; but, in spite of this factor, we find that Carboloy tools stand up very satisfactorily under this service.

Not much can be said at this time on the use of Carboloy as a finishing tool on cast iron, for, obviously, this will require quite a special study. In tests, I have observed that a speed of 300 feet per minute is sufficiently high to take the edge off high-speed steel and other tools almost at once. In fact, in one such test the cast iron acted more like a grinding wheel and wore off the tool as rapidly as it was fed into the work. The Carboloy tool used in a parallel test was ground to a rather keen edge and was able to take a light cut for over a foot in length along a block about six inches in diameter with no appreciable wear on the edge. This test suggested that cast iron is more abrasive at high speeds than steel is, but I am not sure this is correct.

As the hardness of the cast iron decreases, or as the grain becomes more and more open, the abrasion on the tool becomes less and heavier cuts and higher speeds can be used. Abrasion resistance becomes less of a factor in tool performance, and the strength of the tool, particularly in the case of Carboloy, enters more prominently. In practice this is readily taken care of by being sure that a tool of sufficient size is used for the cut taken, for the unit pressure in machining cast iron is not large. Quite naturally this type of iron is most commonly met with in large castings. Here the speeds which can be used are correspondingly small, because large masses of metal are not moved as rapidly as small masses, and the necessity of reducing the time of machining requires the use of heavy cuts. Even this cursory discussion, which cannot possibly depict the situation fully, is probably sufficient to show that the advantage Carboloy possesses over high-speed steel is greatest for small castings, and hard iron, and that it decreases as the size of the castings increases and the hardness of the iron decreases.

Our work on cast iron has shown clearly that Carboloy tools can machine harder and denser grades than can be economically handled by high-speed steel. It is logical to assume that the iron is made soft enough to avoid running up machining costs inordinately, and that the most important factor in the situation is the cutting efficiency of the tool material. It is also logical to assume that practice aims at producing iron which, on the average, is well below the grade which begins to give trouble. Such being the case, an economical advantage is bound to follow the introduction of a cutting tool whose cutting efficiency is well above that of our present tool materials.

Coming to steel, we enter what is probably at once the most important and the most difficult field for Carboloy. The difficulties arise mainly from the high tool pressure involved. Even so, our early tests on annealed tool steel, mild and medium carbon steel, and wrought iron led us to expect that Carboloy would show equally as spectacular a performance here as in the work already mentioned. These expectations have been adequately realized in tests such as the following:

At one time we ran a series of tests on a nickel-steel test log, the Taylor speed of which was about 54 feet per minute under our standard conditions

for testing high-speed steel. We soon found that if we were to get any adequate estimate of the life of Carboloy tools on this log, we should have to increase the speed to around 200 feet per minute. This threw us quite out of the range of speeds used with high-speed steel, and we decided to run the high-speed steel under the conditions set for the Carboloy tools. The calculated tool life came under 30 seconds, while the tool on test failed in 16 seconds, having had its edge burnt off almost at once. The Carboloy tool was then set up in the same way, and after running for one hour the test was arbitrarily stopped for the tool was still cutting and capable of cutting for a much longer period. The difficulties involved in determining the tool life of these Carboloy tools may well be imagined from the results of this test. In fact, they are so great that we do not commonly run the tools to failure, but stop the test at some predetermined point and inspect the edge of the tool to see how it has worn. One of our test logs is a chromium-nickel steel with a Brinell hardness number of just over 250. With a cut of ⅜ inch and feed of 1/18 inch, we found that good high-speed tools fail at 35 feet per minute in about 6 to 8 minutes. We ran the Carboloy tools with the same cut and feed, but at 70 feet per minute, and stopped the test after 10 minutes. The tools showed but slight wear at that point.

In this work on steel we have carried the thought in mind that the principal factor limiting the performance of Carboloy tools is the strength of the material. This is predicated on the use of the proper tool shape, cutting angles, size of tool, etc. To test out this viewpoint we ran a series of tests to determine the proper ratio between the chip cross-section and tool section. These tests showed that normal service may be expected if the chip area is in the order of 1 per cent of the tool area. Expressed otherwise, we may expect good service from Carboloy on steel if a sufficiently large tool be used for the job at hand, provided that the feed be not too great. This, in turn, will vary with the steel machined, so that definite recommendations could be given only for specific cases.

CONCLUSION.

This account of Carboloy has shown that the use of tungsten carbide as a tool material has increased the cutting ability of the tool by a whole order of magnitude. This is the first time this has been done since the introduction of high-speed steel by Taylor and White. Granting this improvement in cutting ability, the extent of the use of Carboloy will depend largely on the cost of operating with Carboloy tools and their output, as compared to that of high-speed steel. The ingredients of Carboloy and the process of making it are expensive, so that we may safely say that Carboloy will cost more than high-speed steel; but we have found by an extended study of many fields that the improved performance of Carboloy tools more than offsets the greater cost of the material. In these cases our shops find that they cannot afford, now, to operate without the carbide tools. If the present limited experience with Carboloy does not mislead, because of its very sensational properties and behavior, further possibilities of development are both manifold and attractive.

The research and development work on Carboloy has been carried out as a large scale investigation, in which members of the staff of the Research Laboratory and of other departments of the General Electric Company have participated. It is due to this large scale, coöperative effort, that we know so much about the production and utilization of Carboloy.—"General Electric Review," November, 1928.

MECHANICAL APPLICATIONS OF CHROMIUM PLATING.*

By W. Blum,† Washington, D. C.

After giving particulars regarding the physical properties of chromium, such as hardness, thermal expansivity, density, melting point, electrical conductivity, and adherence, the author discusses the uses to which chromium plating, by reason of its wear-resisting qualities, has been more or less successfully put: namely, its application to gauges and other measuring devices; to drawing, forming, stamping, and molding dies; to rolls for forming metals; to tools for cutting metal; to bearing surfaces in machinery, etc. He shows how in addition to savings due to the longer life of chromium-plated tools and parts, there are savings much greater in amount resulting from reducing the number of times that machines must be stopped for their replacement.

Two years ago, in summarizing the status of chromium plating at the Annual Meeting of the Society,‡ the author referred to it as the sensation of the plating field. The phenomenal developments in the last two years, especially in the automobile and plumbing industries, have now made chromium commonplace, and before long it will probably entirely supersede nickel as the finish on exposed metal parts of such products.

Simultaneously with the extensive use of chromium plating for the finish on exposed metal, its application for "wear resistance" has received careful consideration in many and varied industries.

In the following attempt to survey the present status of the mechanical uses of chromium plating, the author has acquired most of his information from visits to and correspondence with industrial firms. Experience shows that while laboratory tests are of value for defining the properties of a metal and for indicating its promising uses, the conditions in manufacturing plants often involve so many undefined or uncontrolled variables that the actual value of a metal for a given process must be determined empirically. Such conclusions as will be presented in this paper must be considered as tentative, and are published largely in order to stimulate more extensive quantitative studies upon the value of chromium for various purposes.

Most of the applications of chromium plating depend either upon its resistance to tarnish, or upon its hardness and wear resistance. Some uses, *e.g.*, on plumbing fixtures, involve both of these properties. The present paper will be confined, however, to those articles on which chromium is applied principally in order to increase the resistance to wear or abrasion, and on which appearance is a subordinate or negligible consideration. Even for these uses, however, the protection against tarnish and corrosion that may be furnished by the chromium is an added, though secondary, advantage.

PHYSICAL PROPERTIES OF CHROMIUM.

The value of chromium for any given mechanical application may depend not only upon its "hardness" (however that may be defined), but also upon other properties such as tensile strength, ductility, thermal expansivity, den-

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* Published by permission of the Director of the Bureau of Standards.

† Chemist, Bureau of Standards.

‡ See "Chromium Plating," by Wm. Blum, in "Mechanical Engineering," vol. 49, No. 1, January, 1927, p. 33.

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sity, melting point, electrical conductivity, adherence, and interfacial relations in contact with liquids or solids. Unfortunately, very few of these properties have been quantitatively measured, and even when data are available in the literature, it is not always certain whether they refer to electrolytic chromium or to that produced by other methods and possibly having different composition and properties. Pending the more exact determination of these properties, a qualitative or semi-quantitative discussion of them may be helpful.

Hardness. Of the various means used for measuring the hardness of metals, only the scratch hardness method is applicable to the very thin films of chromium, *e.g.*, 0.0001 inch to 0.001 inch thick, that are usually employed on mechanical equipment. Methods such as the Brinell and its modifications require much thicker deposits in order to eliminate the effect of the base metal. It is not safe to assume that the actual or relative hardnesses of very thick deposits will be the same as those of thin films.

In a recent study of the scratch hardness of electro-deposited chromium, L. E. and L. F. Grant ¶ confirmed previous observations that the hardest chromium is harder than any other metal or alloy thus far tested. It is important to note, however, that they obtained relatively large differences in the hardness of deposits produced under different conditions.

At best the scratch hardness method is difficult and tedious to apply, especially when, as with chromium, the scratch is very narrow. At present, therefore, the method must be considered as a relative rather than an absolute or quantitative procedure.

Some measurements of the Brinell hardness of chromium by F. Adcock § show that the hardness may be very greatly affected by treatment subsequent to deposition. Electrolytic chromium with a hardness of about 600 had, after being heated in vacuo at 900 degrees C., a value of only about 200. When, however, it was heated in hydrogen at 1500 degrees C., the hardness was reduced to about 80. Adcock attributes the initial hardness partly to the presence of hydrogen or oxygen in the deposits. These observations have no direct bearing upon the wear resistance of chromium as deposited, but they emphasize the fallacy of heating to high temperatures (*e.g.*, in order to produce "alloying") deposits which are to be subjected to wear.

Even more important than the measurement of hardness is the relation of the results to the wear resistance under any given conditions. Other conditions of service, however, such as on gauges, dies, etc., may involve so many factors other than simple abrasion that it is unsafe at present to predict the service of a given metal from any simple hardness measurements.

Tensile Properties. So far as known, no data are recorded upon the tensile strength and ductility of electrolytic chromium; probably because of the great difficulty of preparing suitable test specimens. Qualitative tests show that it is extremely brittle, *i.e.*, its ductility is almost zero. This fact largely accounts for the tendency of relatively thick chromium deposits to chip or flake when subjected to impact.

Thermal Expansivity. The adherence of chromium to the underlying surface when heated, either directly as in a glass mold, or indirectly as on a cutting tool or forming die, depends partly upon its coefficient of expansion, or more strictly upon the relation between the coefficients of chromium and of the base metal. The available data on the coefficient of electrolytic chromium are probably not of high accuracy on account of the difficulty of preparing long, coherent specimens. The linear expansion coefficient given in I.C.T. (International Critical Tables) for the range from 0 to 500 degrees

¶ "Trans. Am. Electrochem. Soc.," vol. 53, (1928), p. 509.
§ "Jl. Iron & Steel Inst.," vol. 115 (1927), No. 1, p. 369.

C. (32 to 932 degrees F.) is 8.1×10^{-6}. This value is very similar to those for glass and platinum, and much less than those for iron, copper, nickel, zinc, and most of the common alloys. This fact undoubtedly accounts for part of the difficulty experienced with flaking of chromium from articles subjected to high temperatures in service. It also suggests the possibility that for special uses, alloys with an expansion coefficient closer to that of chromium might be employed.

Density. The density of electrolytic chromium is chiefly of interest because it serves as a basis for the calculation of the average thickness of deposits from their weight and area. So far as known, the density of electrolytic chromium has never been accurately determined. The value of 7.1 for cast chromuim given in I.C.T. may be employed pending measurements on electrodeposited chromium.

Melting Point. The high melting point (1615 degrees C. or 2940 degrees F.) of chromium makes it very unlikely that the plated coating will actually fuse under any conditions to which it is subjected in mechanical equipment, as this melting point is appreciably higher than that of any common metal that may underlie the chromium.

Electrical Conductivity. The accepted value (in I.C.T.) for the resistivity of chromium is 2.6×10^{-6} ohm-cm., a value almost identical with that for aluminum, and less than that of other metals except silver, copper, and gold. It does not follow, however, that the resistance of a contact between chromium and another metal will be low.

Adherence. The occasional failure of electroplated chromium to adhere to the base metal under severe conditions of service is one of its serious limitations.

In general it is not so difficult to obtain satisfactory adherence of the chromium to a plain carbon steel, even when case-hardened, as it is to certain of the alloy steels that are used for tools and dies. A few observations indicate that it is more difficult and requires a higher current density to produce satisfactory deposits on steels containing chromium and tungsten than on other steels.

In preparing the surface it is of course necessary to insure perfect cleaning, and especially the removal of any oxide coating. In addition, it has sometimes been found advantageous to employ a reverse current, *i.e.*, to make the article the anode for a minute or less before making it the cathode and depositing upon it.

Interfacial Relations. It has been frequently observed that many liquids, including water and even molten metals, do not readily wet a chromium surface. This behavior, which may be due to surface films, materially increases the tarnish resistance and protective value of the chromium coating. Similar observations have been made regarding the contact of chromium with metals or other solids. Thus it is claimed by many that chromium-plated files do not hold particles of metals or other materials as tenaciously as do the unplated surfaces.

The value of chromium upon bearing surfaces may depend not only upon its coefficient of friction under given conditions, but also upon its ability to resist abrasion and chemical action, and thus to maintain for a longer period the initial condition of the surface. A few preliminary observations by W. H. Herschel at this Bureau indicate that with a given oil a slightly dull surface of chromium has a lower coefficient of friction than a polished surface. The possible significance of this difference (which is observed also with other metals) is that the chromium, because of its hardness, will preserve this dull surface better than other metals. Another possible advantage of chromium upon a bearing surface is that it may then be possible to lubri-

cate with an oil such as lard oil, which produces a low coefficient of friction, but which cannot be used on those bearing metals which are attacked by any free acid liberated from the lard oil.

TYPICAL APPLICATIONS.

The uses for which chromium plating has been tried or suggested are so numerous, and many are apparently so unrelated, that it is difficult to devise any logical or helpful classification of them. For convenience they will be divided into devices employed for the fabrication of articles from metals or other materials which include those used for (1) measuring, (2) forming, and (3) cutting, and applications to improve the operation of finished machinery or equipment.

MEASURING DEVICES.

Chromium plating has proved especially valuable on measuring devices, because its resistance to abrasion decreases the tendency for any change in dimension, or for any obliteration of graduation marks. The latter factor justifies its use on linear scales, verniers, micrometers, tapes, etc. During the past few years it has been applied successfully upon the 50-meter base-line tapes used by the U. S. Coast and Geodetic Survey. For this purpose the chromium is plated for only a short distance on each side of the principal graduations. Experience has shown that on the chromium-plated tapes the graduation marks retain their definition much better than on the plain tapes.

Chromium has been more extensively and more successfully applied upon plug gauges than on any other measuring devices. Of the numerous replies received on this subject, all were favorable except one, and the life of the plated gauges in service was estimated to be from three to ten times that of the unplated gauges.

Although it is possible with proper control of the plating process to deposit upon a gauge exactly the requisite thickness of chromium, and to use the gauge without subsequent lapping, experience has led in almost every case to the deposition of a somewhat thicker coating, the excess of which is then ground or lapped off. The data received include thicknesses from 0.0002 inch to 0.004 inch. The thickest coatings were applied for bringing greatly undersized gauges to dimension. In general the chromium coating should be thick enough so that it will not be penetrated when the gauge is worn down to its lower wear limit. It is then a simple matter to strip off the chromium (*e.g.*, by a reverse current in a sodium hydroxide solution) and to replate to the desired dimension. While of course the minimum thickness required will depend upon the dimensions of the gauge before plating, there is no evident advantage in applying more than 0.001 inch of chromium, and for many purposes half that thickness is adequate. If the gauge is made to be about 0.0008 inch undersize (in diameter) a deposit with an average thickness of 0.0006 inch, corresponding to an increase in diameter of 0.0012 inch, will usually be sufficient to leave a thickness of 0.0004 inch after lapping to the right size. If then the wear limit of the diameter is 0.0003 inch, the gauge will still have a coating of chromium of about 0.00025 inch thick when it is returned for replating.

Although chromium-plated thread gauges are now used in several plants, there is still much uncertainty and skepticism regarding their reliability. This doubt arises from the difficulty of depositing chromium uniformly upon the surface of the threads. In any plating process the deposit is always thinner in a depression than upon a projection, and this difference is accen-

tuated by the notoriously poor "throwing power" of the chromium-plating bath. As a result of the uneven distribution of chromium upon the threads, not only the diameter of the gauge, but also the thread angle, is altered.

The few experiments made with thread gauges show that when any appreciable thickness of chromium is applied the changes in pitch diameter and and major diameter and in the included angle, are likely to be greater than the normal tolerances for such dimensions. It will therefore usually be necessary to regrind the gauges after plating, unless they have been previously so ground as to allow for the uneven distribution of the chromium. The latter procedure is probably feasible if a large number of similar gauges are being made and plated.

The data obtained regarding ring and snap gauges indicate that chromium plating increases their life to about the same extent as it does on plug gauges. It may safely be stated, therefore, that chromium plating will prove valuable upon any measuring device which is subject to abrasive wear in service, provided the shape is such that the chromium can be applied with reasonable uniformity.

FORMING OF METALS.

Drawing Dies. The information received shows an apparent contradiction in that dies and mandrels used for tube drawing were generally reported as satisfactory (with one exception), while wire-drawing dies were usually unsatisfactory. The latter were reported as failing through flaking or peeling of the chromium, and subsequent scratching of the wires. The only obvious explanation of this discrepancy is that the apertures in the wire dies are usually much smaller, and therefore more difficult to plate uniformly than those in the tube dies.

In connection with the manufacture of hot-rolled seamless steel tubes, the successful use of chromium-plated drift balls was reported.

Forming Dies. Very favorable reports were received regarding the value of chromium plating upon dies used for forming sheet steel and brass. In some cases the life of the dies is increased up to eight times the normal service. One special advantage observed with the chromium-plated surface is that the metal does not stick to it as much as to steel. It is significant that the thickness of the chromium coating on these dies is usually less than 0.0005 inch.

Stamping Dies. In those cases where the metal is formed or a design produced upon it by a sudden impact instead of by a steadily applied pressure, the chromium coating is of doubtful value. This is because under such severe conditions the chromium tends to flake or chip, probably because the underlying metal, even when it is case-hardened, is at least temporarily deformed. In such cases success is more probable with thin than with thick coatings. A few experiments, not yet completed, upon coinage dies at the U. S. Mint in Philadelphia, illustrate this difference. Those dies with a coating of 0.0005 inch or more of chromium all failed in a comparatively short time. Those with only 0.0002 inch of chromium lasted slightly longer than the steel dies, and yielded consistently sharper impressions. While the advantages gained with the chromium-plated dies have not yet warranted their general application at the Mint, they are still under consideration.

In connection with these experiments it was found that the hardened steel collars which hold the coin blanks and fix the diameter of the coins, could have their life greatly increased by chromium plating. Thus for the five-cent coins, composed of a nickel-copper alloy, the average service of the chromium-plated collars is about 600,000 pieces, *i.e.*, three times that of the

unplated collars. As moreover the chromium can be stripped at intervals and the collars replated, their life is made almost indefinite and, what is more important, the resultant coins are of more nearly uniform size.

One plant reported favorable results with dies used in hot forging. If this experience is confirmed, the improvement may be due at least as much to the protection furnished by the chromium against oxidation as against abrasion. This application is somewhat similar to the use of chromium on glass molds that has been reported both in Germany and in America.

Both spinning and burnishing tools may be classified as forming devices, even though the action of the latter is confined to the surface. Several favorable reports were received upon both of these applications of chromium, though one person found difficulty with flaking of chromium from the burnishing tools. It is not clear whether this discrepancy was due to the quality of the plating or to the character of the metal burnished. A few observations at the Bureau upon spinning tools showed very favorable results for the chromium.

Molding Dies. One of the most successful applications of chromium is upon dies used for molding plastic materials such as rubber, bakelite, ceramic clays, etc. The increased service observed is due not only to the resistance of the chromium to abrasion by particles in the molding compound, but also to corrosion by sulphur, phenol, water, or other substances present in the materials. Large chromium-plated metal sheets are being used successfully in the presses employed to produce insulating materials such as those composed of fiber and a phenol condensation product.

Rolls for Forming Metals. The great size and weight of the rolls used in many operations renders their plating somewhat difficult. Rolls used for finishing sheet metal would almost certainly have their life increased by plating.

Upon rolls used for crushing hard materials such as rocks, the chromium may be less promising, as the conditions of service are very severe, and are likely to lead to fracture and flaking of the chromium. In some cases chromium-plated rolls used for crushing softer materials such as cereals, have proved very much superior to hardened steel.

CUTTING OF METALS.

The data received regarding chromium on tools used for cutting metals are more variable and less favorable than those for any other uses. The general difficulty may be summed up by saying that if the chromium is thick enough at or near the cutting edge to exhibit its great hardness, it is likely to fracture, and if too thin, it soon wears off the edge and offers little advantage. The value of chromium is no doubt affected by such factors as the angle and type of the cutting edge, the speed of cutting, and the material being cut. In at least a few cases favorable results have been obtained by plating only one side of the tool with a fairly thick chromium deposit. The tool can then be ground repeatedly upon the steel side, thus always leaving a cutting edge of chromium.

Blanking dies furnish a good illustration of the difficulties with chromium plating, especially when they are used on hard metals such as steel. The impact is such that any fairly thick deposit is likely to flake, and thin deposits usually add but little to the service. On the other hand, such tools as milling cutters, reamers, drills, and taps have frequently shown a material increase in service after plating. The most consistent gains are obtained when cutting such substances as slate, asbestos board, and bakelite, which materials, though commonly referred to as "soft," cause rapid wear of steel tools.

The experience with saws of various types is like that with other cutting tools. If a thick coating is applied there is a marked tendency for the formation of nodules or "trees" upon the points of the teeth. These dull the points, and if, as usually occurs, they break off in service they leave the teeth rough and irregular. For such articles it is therefore preferable to use relatively thin coatings. This conclusion is confirmed by the results reported for hack saws. Even with the thinner coatings they were not so satisfactory for cutting steel as for such materials as slate and asbestos.

In this connection a few experiments are in progress at the Bureau by J. R. Freeman, Jr., upon cutting steel rails with a power saw and high-speed (tungsten) steel saw blades. Some difficulty was encountered in getting a uniform coating of chromium on this alloy, and a very high current density was required. Owing to the tendency to pile up chromium on the teeth, the thickness there was indeterminate, but certainly much greater than the average thickness computed from the current density and time of plating. With an average thickness of about 0.0004 inch there was very pronounced nodules on the teeth, and it required considerably longer to cut through a rail than when using the unplated blade. Even with much thinner coatings, *e.g.*, those having an average thickness of about 0.00005 inch, the initial speed of cutting was slightly decreased, showing that there was some dulling of the edges. Some time will probably elapse before conclusive data upon the useful life of the plated saws will be obtained.

The results reported for files were somewhat similar to those for saws, in that any appreciable thickness of chromium tends to dull the files. It was reported by several persons that chromium-plated files show much less tendency to clog in use than unplated files. Whenever a material tends to fill the files, the use of light chromium coatings may be justified even though the useful life of the file may not be greatly increased. In some cases, however, an increase to double the original service was obtained.

A few reports upon woodworking tools, including saws, chisels, and lathe tools, show that their life is very greatly increased by the use of chromium coatings. Results with rock drills are still uncertain. Experiments are also being made by one firm upon chromium-plated plowshares. For this purpose the resistance to corrosion may be helpful, even if the actual cutting edge is not greatly improved.

OPERATING MACHINERY.

In spite of the apparently obvious applicability of chromium upon all parts of machinery that are subject to wear in service, such use is still far from being a general or even a preferred practice. The failure to adopt chomium for such purposes may be due to various causes, including the size or inaccessibility of many of the parts, and the fear that if the chromium should become detached from a bearing surface, the particles would serve as an abrasive and cause permanent injury to the mechanism. While the latter possibility warrants careful consideration and proper caution, the probability of its occurrence is not evident from the meager data available. If, as was suggested earlier in this paper, a lower coefficient of friction can be obtained and maintained on a chromium surface than on other metals, the use of chromium on bearing surfaces may prove beneficial. There is no justification, however, for assuming that the use of chromium will obviate the necessity for lubrication.

Although the automobile engine is a mechanism upon which the application of chromium would appear promising, very few such uses have ever been made on a production scale. Chromium-plated piston pins, employed

on one make of car, owed their selection as much to protection against corrosion by sulphur compounds as to resistance to abrasion. Efforts to plate pistons with chromium have not been entirely successful, though considerable attention is now being given to this possibility on aircraft engines. It has been recently reported that on one of the cars in the Indianapolis races chromium-plated steel journals were successfully used in aluminum-alloy bushings. If this experience is confirmed it indicates that the successful use of chromium on bearings may depend upon and permit the use of bearing metals different from those commonly used.

In a few cases chromium-plated gears have proved satisfactory. Such uses are, however, most promising upon light equipment such as speedometers, counting machines, etc. For such purposes they have reduced the noise of operation and also increased the useful life.

One strikingly successful application of chromium plating has been on 9-inch piston rods of Diesel marine engines. These rods run in a cast-iron packing with only moderate lubrication. It was found that the application of 0.003 inch of chromium to the surface of the rods resulted in smoother operation and less difficulty in lubrication. The unplated rods lost about 0.001 inch in diameter for every 5000 miles of service, while the chromium-plated rods required 45,000 miles of operation to produce this same loss in diameter. Incidentally these piston rods, which were water-cooled, were also plated on the inside with chomium, which greatly reduced the corrosion.

Although printing plates are not ordinarily considered as a part of a machine, they virtually become a part of a printing press when in use. The experience with printing plates may therefore be suggestive. Currency plates consisting of electrolytic nickel coated with chromium yield about twice the number of impressions obtainable from case-hardened steel plates. Curved stamp plates, made of case-hardened steel and chromium plated, yield about double service, and can be stripped and replated several times before being worn out. Nickel electrotypes when chromium plated produce from three to five times the normal number of impressions, and are therefore extensively used for long editions, *e.g.*, those of wrappers, labels, and cartons. It should be noted, however, that in all these applications the chromium is valuable for its resistance to abrasion, and does not materially add to resistance to deformation or fracture if for any reason the plate is subjected to an excessive strain or sudden shock.

CONCLUSIONS.

Chromium plating owes its application upon mechanical equipment primarily to its great hardness, as exhibited in its resistance to abrasion. The chief limitation in the use of chromium for such purposes is its extreme brittleness, which may cause it to crack and flake when deformed. The most successful mechanical uses of chromium are upon measuring instruments such as gauges of all types, the service of which is often multiplied several fold. Upon forming and molding dies it is generally satisfactory and beneficial, especially if the conditions do not involve too severe impacts. Upon cutting tools it is of doubtful value, though in numerous applications it has proved successful. Upon moving parts of machinery there have been but few successful applications, but these indicate that with further study many such uses may be developed.

It is impossible to estimate even roughly the savings that have been or may be accomplished through the use of chromium on mechanical equipment. The cost of the tools or devices that may be dispensed with because of the greater life of those that are chromium plated, represents only a small part

of the economic gain. The money saved in reducing the number of times that a machine must be stopped for replacement of a tool or die may amount to many times the cost of the device. Perhaps the greatest gain is the somewhat intangible but far-reaching benefit arising from the manufacture of more uniformly dimensioned parts, whereby the useful life of a machine such as an automobile may be materially lengthened.

Chromium plating is not a panacea for wear. An everlasting tool or machine is as visionary as perpetual motion. Chromium plating has, however, solved many machine-shop problems, reduced costs of operation, and improved the quality of the products. When we recall that almost all this progress has been made in less than three years, there is good reason to hope and to believe that with the large number of investigators now at work on this subject, even greater results may be expected.—" Mechanical Engineering," December, 1928.

STEAM-TURBINE BLADING MATERIALS.

By A. Bodmer,

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The author gives the results of study and research in turbine blading materials extending over more than twenty years. This account was prepared by R. H. Andrews, Paris correspondent of " Power," on the basis of a profusely illustrated article in the April and May, 1928, issues of " Chaleur et Industrie," which should be consulted by specialists interested in metallurgy.

Recent progress in steam engineering seems to be turning definitely toward higher pressures, but high throttle pressures have a serious disadvantage. With the same total steam temperature and condenser vacuum the higher the initial pressure the greater will be the amount of moisture in the steam at the end of expansion, and this means a corresponding increase in fluid-friction losses in the lower stages of the turbine, not to mention the erosion of the turbine parts.

Two expedients have been considered to reduce the amount of moisture in the exhaust steam—resuperheating and increasing the initial steam temperature. The first method has already been widely applied in the United States, but has, as yet, found little favor in Europe, where interest is mainly concentrated on the second remedy, that of increasing the initial steam temperature.

A comparison of these two methods is beyond the scope of this article. It may be said, however, that resuperheating works, but requires a complicated and costly installation; whereas, high initial superheat has as yet received insufficient systematic study and application, but presents the advantages of simplicity, low first cost and higher thermal efficiency.

The idea of using higher steam tempertures is gaining ground both in Europe and in the United States, but it meets a great obstacle to its application in practice from the lack of confidence on the part of many operating engineers in the mechanical strength of superheater and turbine materials at these high temperatures, and particularly those materials available for the construction of the turbine parts exposed to direct contact with the steam, such as the fixed and moving turbine blading and the nozzles.

The object of this article is to review the materials used to date for turbine blading and to show that there is no longer any obstacle to the use of materially higher steam temperatures; for materials have been available for at least ten years which have proved their ability to withstand the action of high-temperature steam.

PRINCIPAL TURBINE-BLADING MATERIALS.

In the early days of steam-turbine construction the principal materials used for reaction blading were bronze and brass, while carbon steels or low-content nickel steels were preferred for impulse blading. In recent years the use of these materials has not been discontinued, but many others have been tried out. The most interesting among these new materials are ferro-nickels, nickel brass (copper base), copper-nickel alloys (copper base), nickel-copper alloys (nickel base), steels of high nickel or chromium content or containing both these elements, and ferrous alloys of high nickel and chromium content.

Brass has generally proved a satisfactory material for turbine blading, within certain limits. Its principal advantages are its resistance to chemical corrosion by steam carrying impurities, and facility of working. The principal defect of brass lies in its unsatisfactory mechanical properties, especially at high temperatures. It cannot be used above 400 degrees F.

Brass is still used by many turbine builders, but only for the medium-pressure stages of large units, or the medium- and low-pressure stages of small and medium-sized turbines.

NICKEL BRASS.

Nickel brass, or bronze, is now made in different compositions. In addiiton to its greater strength, nickel brass shares with ordinary brass the advantages of ease of working and resistance to corrosion by impure steam. But it also has the same defect, loss of strength at higher temperatures. Its use is therefore confined to medium- and low-pressure stages of turbines. As compared to ordinary brass, nickel brass finds a more extensive field in the direction of low-pressure blading, owing to its higher mechanical strength.

COPPER-NICKEL ALLOYS.

A copper-nickel alloy consisting of about 80 per cent copper and 15 per cent nickel, with various other constituents, retains its strength better than nickel brass or ordinary brass, and may safely be used for temperatures as high as 650 degrees F. However, its use is practically limited to medium- and low-pressure stages. The mechanical properties of this alloy are about the same as those of nickel brass. It can be used only in turbines of moderate peripheral speeds.

NICKEL-COPPER ALLOYS.

A nickel-copper alloy consisting of about 65 per cent nickel, 28 per cent copper, and the balance of various other metals, was developed some 20 years ago. It has certain features of unusual interest, principally its resistance to corrosive action. Its properties are not seriously affected by heat, provided the temperatures do not materially exceed 550 to 600 degrees F. This alloy becomes fragile by the effect of temperature alone, around 900 degrees F. Another limitation to the extensive use of this nickel-copper alloy in large modern turbines is its insufficient resistance to the erosive action of moisture in the steam. This defect limits the use of this alloy to turbines of moderate peripheral speeds.

The behavior of this nickel-copper alloy under the action of superheated steam is satisfactory, provided the temperatures are kept relatively low; but it does not seem suited to blading in the high-pressure stages of turbines

using high-temperature steam. J. F. Saffy recently placed a sound bar of nickel-copper alloy under the action of superheated steam at 750 degrees F., for one month. At the end of this period a bending test revealed the presence of deep intercrystalline crevices, indicating advanced disintegration of the metal under the action of the superheated steam.

FERRO-NICKEL ALLOYS.

The behavior of this alloy in the presence of high-temperature steam recalls that of ferro-nickels. At about the same time that the above-mentioned nickel-copper alloy was first tried out for turbine blading, it was thought that the high resistance to oxidation and corrosion of ferro-nickels of 25 per cent, 33 per cent and even 36 per cent nickel content would make these materials suitable for the construction of turbine blading. The results were a complete failure. These alloys, though resistant to a considerable extent to oxidation by air or rain, are subject to rapid corrosion in the presence of steam.

Among all the materials used in recent years for steam-turbine blading, nickel steels containing approximately 5 per cent nickel are undoubtedly the most commonly used, both for high-and low-pressure stages, and especially for impulse turbines, and deserve special consideration. These materials have shown remarkable qualities for operation in superheated steam as well as in the low-pressure stages, provided the vacuum is not too high. In spite of this superiority, however, they are still deficient in ability to resist corrosion and erosion. Five per cent nickel steels are at present the most broadly used of all turbine blading materials; but this fundamental defect cannot be denied. In the action of steam upon this material, the most important factor is the steam temperature.

RECENT DEVELOPMENTS.

Steam temperatures of 850 to 950 degrees F. still seem prohibitive to a great many operating engineers. Yet from the experience of the Langerbrugge central station in Belgium which has been operating at 850 degrees F. for several years; and from sporadic experiences such as that in the Gennevilliers central station; also from the remarkable results of recent metallurgical research in the development of new turbine materials, it seems very probable that we shall shortly have at our disposal materials and processes allowing the construction of reliable superheaters capable of producing steam at these temperatures and at any pressures within the range of power practice.

FIVE PER CENT NICKEL STEEL.

Most of the alloys that have served in the past for turbine blading, and those that are still in use, have been reviewed herein, and it may be concluded that not one of these, not even 5 per cent nickel steel, fulfills all the conditions required by modern practice.

The best of these materials is 5 per cent nickel steel, and various expedients have been tried to make it better yet. For example, attempts have been made to subject blades of 5 per cent nickel steel to some process for the purpose of giving them a protective coat of some unoxidizable or less corrodible metal, such as chromium, tin or zinc. A practical experiment was tried at the Gennevilliers station in Paris, where the blades in three last stages of a 40,000-Kw. impulse turbine were tinned by immersion in a tin

bath, and afterward carefully polished. The result was not satisfactory, for after three months' service the coat of tin had completely disappeared and the metal surface underneath was being rapidly oxidized.

To the best of the writer's knowledge the electroplating of turbine blades with chromium has given no appreciable results.

EFFECT OF HEAT TREATMENT.

In order to give more effective resistance against erosion, several turbine builders have advocated the use of metals subjected to a heat treatment, for the purpose of raising their mechanical characteristics. A hardening effect may readily be obtained in this way, but the metal frequently becomes brittle; rupture of blades becomes more frequent, possibly owing to the formation of surface crevices during the heat treatment.

In the face of the exacting conditions imposed by modern turbine practice on the one hand, with ever-increasing capacities and higher peripheral speeds, and on the other hand by the failure of existing blading materials to fulfill the new requirements, a considerable amount of research has been undertaken with a view to replacing or improving these materials. Most of this work has covered ferrous alloys containing nickel or chromium, or both, in considerable proportions, and has given variable results.

Certain austenitic alloys containing about 8 per cent nickel and 18 per cent chromium have been presented by several concerns. Their excellent resistance to certain acids and to sea water gave rise in Germany to the hope that they might be used at least for stationary turbine blading. According to the latest information these alloys have not come up to expectations. They are extremely difficult to machine, and their heat-treatment is delicate.

The most important of these modern blading materials seem to be steels containing a considerable proportion of chromium, with or without a small quantity of nickel, and alloys containing a large proportion of both nickel and chromium.

CHROMIUM STEELS.

Steel carrying 13 per cent of chromium was first produced in England and is now being manufactured in most countries producing special steels, under a considerable number of trade-marks. These are of variable value, depending on the technique of the manufacturer. In France and some other countries they are called "unoxidizable," but this term gives an incorrect idea of their value. In reality these products offer a certain resistance to oxidation and to certain causes of corrosion; but these properties are dependent on the exactness of their process of manufacture and treatment, and considerable care must be observed in their use, so as not to impair their qualities.

Two grades, or general groups of these products are produced; a hard grade and a soft grade. The resistance of the first to oxidation is dependent on the exactness of the heat treatment, consisting of quenching and annealing; and the perfection of the polish of the metal surface. Attempts to apply this steel to turbine blading have resulted in serious trouble. For example, in the case of the fixed blading the roots of the blades are buried in the cast iron or cast steel of the turbine casing during the casting of the latter; and it was found that the sudden heating and subsequent cooling of the casting process completely destroyed the effect of the heat treatment of the blading metal at the root of the blades, and that they became brittle and had lost most of their capacity to resist oxidation.

The soft grade does not require as strict observance of temperature conditions in its heat treatment as the harder grade, though its resistance to oxidation is still dependent on this treatment. But the maintenance of the most perfect possible polish of the surface of the blades is still necessary. This material is therefore suitable for the rotor blades. But the troubles encountered in the manufacture of the fixed blading are common to both grades. In fact, these troubles are inherent to all materials such as steels which become tempered and undergo molecular transformations under the influence of temperature changes. The contact of the hot molten metal with the roots of the blades produces molecular transformations that cannot be foreseen and leaves the metal in an unknown condition.

EFFECT OF SURFACE POLISH.

Furthermore, as was seen above, the resistance of 13 per cent chromium steels and iron to oxidation and corrosion is dependent on the surface polish. Consequently, if this polish becomes impaired by erosion, the metal loses much of its resistance to oxidation. A special heat treatment is therefore often resorted to after the blades have been completely machined, for the purpose of hardening them and so making them less sensitive to erosion. However, this operation is costly and extremely delicate.

About twelve years ago there was developed in France a ferrous alloy containing a large percentage of nickel and chromium, and known by the name of "A.T.V. Alloy." It is really 36 per cent ferro-nickel to which is added a sufficient proportion of chromium to correct the defects outlined above, and particularly its sensitiveness to intercrystalline corrosion under the action of steam.

EXPERIENCE WITH "A.T.V." ALLOY.

The writer's first experience in the application of this alloy to turbine blading began in 1920, in the central station of the French naval arsenal at Toulon. The operating conditions of this station were particularly exacting. It was used mainly for stand-by service, most of the power needs of the arsenal being supplied from the system of a local hydroelectric power company. The generating units, four in number, were driven respectively by two 2400-and two 3500-H.P. Zoelly impulse turbines. Furthermore, sea water is used for condenser cooling, and in spite of the utmost care in the upkeep of the condensers small quantities of chlorides leak into the condensate and are entrained by the steam.

The turbine blading, which was of 5 per cent nickel steel, gave considerable trouble. It was replaced every fourth or fifth year, and long before these replacements, the blades were so deeply cut along the edges and pitted by erosion and corrosion that the efficiency and general operation of the turbine were considerably impaired.

EXPERIMENTS WITH A.T.V. ALLOY.

The writer had proposed in 1916 to try the A.T.V. alloy; but the production of this material during the war was very small, and only in 1920 could the change be made. The first trial was made on the two 2400-H.P. turbines, the nozzle vanes of those stages closest to atmospheric pressure being replaced by A.T.V. In 1922 all the nozzles and rotor blading of the low-pressure stages of one of the 3500-H.P. turbines were replaced by A.T.V.

The chief engineer reported in 1924 that careful inspection of the turbines at that date showed no trace of corrosion or erosion of the replaced nozzles

and blades. At the present time, after more than seven years of intermittent service of the most exacting kind, the nozzles and blading of the three turbines are still intact.

In 1919 the writer had already started a series of tests in the laboratories of the Société Alsacienne de Construction Mécaniques for the purpose of observing the resistance of various blading materials of French manufacture to erosion and corrosion. An expansion nozzle fed by a steam line with steam containing a slight amount of moisture was disposed so as to direct a steam jet, at the velocity of about 3000 feet per second, against a pair of turbine blades fixed side by side. Each test lasted several days. The behavior of the A.T.V. alloy was in every case materially superior to that of every other alloy tested. Following these results, the Société Alsacienne and several other turbine builders have been developing the use of A.T.V. for fixed and movable blading, in all cases where corrosion and erosion are probable.

One of the interesting features of A.T.V. is that it can readily be used for fixed blading and nozzle vanes of impulse turbines. As previously mentioned, the roots of these vanes are buried in cast steel or cast iron. During the operation of casting, these vanes are subjected at their root, and in the case of the first-stage nozzles, which are very short, throughout their entire length, to high temperatures. These temperatures have no effect on the mechanical properties of the A.T.V. alloy. The micrographic structure of the alloy does not change, and it retains all its properties of resistance to corrosion and erosion.

Cast iron is materially more adherent to the A.T.V. alloy than to any other blading materials. Tinning of the roots of the blades before casting is necessary with most other steels, but not with A.T.V.

In a recent experiment 13 per cent chromium steel and A.T.V. were used under identical operating conditions, at the Gennevilliers central station.

When the last two 50,000-Kw. generating units (Nos. 7 and 8) of this station were ordered, the specifications provided that all blading, fixed and moving, was to be of "unoxidizable" materials. The two units were built by different manufacturers. One of these chose as blading material 13 per cent chromium steel for the high-pressure stages, brass for the medium-pressure and the first of the low-pressure stages, and 13 per cent chromium steel hardened by heat-treatment after completion of the blades for the last of the low-pressure stages. The other manufacturer chose A.T.V. alloy throughout.

These two units have been in service for about one year. The A.T.V. blading, both fixed and moving, is still in perfect condition. At the last inspection this unit had operated about 2700 hours, and no trace of either corrosion or erosion could be detected. During this period the throttle temperature, which should normally have been 700 to 720 degrees F., frequently exceeded 750 degrees F., while the vacuum in winter frequently reached 29.4 inches, indicating a probable moisture content in the exhaust of about 12 per cent.

The other unit was inspected after 1500 hours of service. In the high-pressure section many of the rotor blades of 13 per cent chromium steel were found to be more or less severely chipped, and several stages had to be rebladed. The brass blading of the medium-pressure stages was found in perfect condition with the exception of a few blades, both fixed and moving, that had been distorted by particles of metal from the damaged high-pressure blading. The moving blades of the low-pressure stages, which were of hardened 13 per cent chromium steel, were considerably eroded and slightly corroded.

TURBINE BLADE MATERIALS.

Brass. An alloy of low mechanical strength, impracticable for use in superheated steam owing to molecular instability; not to be recommended for low-pressure blading, owing to its lack of resistance to erosion. Generally used only for medium-pressure blading, provided peripheral speeds are not too high.

Nickel-Bronze and Copper-Nickel. Somewhat superior to brass; may be used for steam temperatures up to 650 degrees F. Insufficient resistance to erosion. Their mechanical properties, which are superior to those of brass, adapt them for use in medium-pressure stages.

Nickel-Copper. Almost unoxidizable at atmospheric temperatures, but questionable in the vicinity of 750 degrees F., at which temperature it is rapidly disintegrated by the action of superheated steam. Insufficient resistance to erosion.

Five Per Cent Nickel Steels. Excellent material for blading in all stages; stands up well in high-temperature steam, and resists erosion, provided the vacuum is not too high. Its main defect is insufficient resistance to corrosion; should never be used when salt water is used for condenser cooling.

Twenty-five and 36 Per Cent Ferro Nickel. Materials unfitted for use in steam.

Thirteen Per Cent Chromium Steels. These materials can be used for high-pressure blading, provided the steam temperatures are not too high. They are imperfectly suited to medium-pressure blading, because they are not unoxidizable. Their unsatisfactory resistance to erosion does not adapt them for low-pressure blading. These materials must be used in the heat-treated state, therefore in an unstable molecular condition under variable temperatures.

Ferrous Alloys with High Nickel and Chromium Content. These materials stand up well under all steam temperatures within the range of turbine practice. Their resistance to oxidation and corrosion under conditions of turbine operation is apparently indefinite, even when chlorides and acids are present in the steam. Their resistance to erosion is excellent, even with very high vacua. In every station in which these materials have been used to date, their behavior is reported to be excellent.

SURFACE AND BODY RESISTANCE TO CORROSION.

The essential difference between 13 per cent chromium steel and the A.T.V. alloy is that the former has a *superficial resistance* to corrosion and erosion, which is dependent on the surface polish; whereas the latter is equally resistant throughout to corrosion, and its uncorrodibility is entirely independent of the condition of its surface. Furthermore, temperature changes, even beyond the range of normal heat treatments of steels, have no effect either on the corrodibility or on the crystalline structure of the A.T.V. alloy; for it is mainly austenitic in composition and does not undergo any molecular changes with heating or cooling. This property is especially valuable in fixed blading, the roots of which are subjected to the temperature of molten cast iron during the casting of the casing.

Should power-plant practice so develop as to require considerably higher steam temperatures, the manufacturers of A.T.V. have another alloy, A.T.G., whose characteristics are still superior to A.T.V. at high temperatures.—"Power," October 23, 1928.

NOTES ON BRASS MELTING.

By a Metallurgical Chemist.

Despite the fact that the manufacture of non-ferrous alloys dates back to about the year 1000 B. C., and is therefore one of the oldest arts in the world, it remains true today that some crude and wasteful methods of manufacture are still employed in many of our brass foundries, which fact is all the more remarkable when the numerous and exhaustive researches which have been carried out in this connection are considered. In part this state of affairs may be due to the rigid conservatism with which old and antiquated methods are clung to, and, indeed, in some instances such methods are looked upon as secrets of manufacture which should be closely guarded from competitors. This, naturally, does not make for progress, but results in some foundries making the same old mistakes year after year, even though they meet with whole batches of failures.

Although, perhaps, non-ferrous metallurgy has not received quite the same amount of attention that has been bestowed upon iron and steel, yet there have been certain broad and simple lines formulated which must be followed if successful results are to be obtained at all consistently, and the following notes, although they are not intended to be by any means exhaustive, indicate a few common faults which are often met with, and which cause a good deal of trouble.

Brass foundry work may be broadly divided into two classes—the first being that in which only virgin metal is used, and the second that in which scrap metal is resmelted, either alone or in conjunction with some virgin metal. The making of alloys from virgin metal is, of course, a much simpler process than when scrap is introduced, but as scrap is bound to be made in all foundries, its subsequent refining and resmelting are important. The first essential in dealing with scrap is to make quite certain that all the various classes of scrap are kept entirely by themselves, which means that the machine-shops must be adequately provided with clearly marked bins for the reception of every sort of alloy which they use, and, of course, the same holds good for the foundry itself. The indiscriminate mixing of all kinds of scrap in one common receptacle is exceedingly bad practice and leads to endless trouble.

As a general rule, three or four different classes of scrap will be collected, which are 60 per cent copper, 40 per cent zinc alloy; 70 per cent copper, 30 per cent zinc alloy; 88 per cent copper, 10 per cent tin, 2 per cent zinc alloy—*i.e.*, a bronze; and, perhaps, an alloy of the manganese bronze type, which may contain copper, zinc, aluminum, manganese, and iron. Now it may appear that there can be no harm in mixing 60/40 and 70/30 brass together, but actually it is not advisable to do so, for several reasons. It is clear, at the outset, that the resulting alloy will be neither one nor the other, and an excess of zinc will have to be added to make the alloy into 60/40 brass, because the 70/30 alloy cannot conveniently be made by adding pure copper. Moreover, 70/30 alloy is a cold-working alloy, whilst 60/40 is a hot-working alloy, and for this reason some 1 per cent to 2 per cent of lead is added to the latter alloy to assist it in being more easily hot rolled or extruded, whilst, at the same time, it assists in improving its machinability. Lead is, therefore, of distinct benefit to the hot-working alloy, but the same alloy, in amounts exceeding a trace, is decidedly detrimental to the 70/30 alloy. It becomes evident, therefore, that to obtain the best results these two alloys should be refined separately. It is, perhaps, scarcely necessary to mention that any bronze alloy—*i.e.*, any alloy containing copper and tin—should,

under no circumstances, be allowed to contaminate any plain copper-zinc alloy, because in many instances even a slight trace of tin is exceedingly harmful to a pure copper-zinc alloy.

Impurities are always present in all commercial alloys, but the amount of these which are introduced frequently are the deciding factors which determine whether a cast is to be successful or not, and so it behooves one to pay every attention to the amounts of such which will be present in the finally cast alloy. The metal iron is one of the impurities which can be quite accidentally added to a pot of metal to excess, and the presence of too much iron is not to be recommended, it being, in some cases, very deleterious. Its presence may be accounted for in two ways. The first is simply due to allowing brass scrap to become mixed with some iron or steel turnings, most probably in the machine shops; the remedy is, of course, obvious. The second way in which iron may inadvertently be introduced is, however, not so obvious, and, indeed, in some instances its presence is at first difficult to account for, and may appear to be something of a mystery. If, however, it is borne in mind that iron is quite soluble in molten brass, then the solution of the difficulty becomes considerably clearer. It is usual to finally stir all melts of non-ferrous metals with an iron rod, and it is entirely obvious that if the stirring operation be performed slowly, so as to allow the iron rod to become as hot as the metal itself, then there is every likelihood of some of the iron being dissolved in the alloy. Stirring should, therefore, be performed as quickly as ever possible, and if the end of the rod is protected with a fireclay sheath then so much the better. This possible way of introducing iron is, of course, fairly obvious, but there remains a further manner in which it is often introduced, and which at first sight may not be so obvious. As is well known, any alloy containing zinc will, when overheated during melting, give off copious supplies of a dense white substance, which actually is oxide of zinc, and as this means that a certain amount of valuable zinc is lost into the atmosphere, the smelter is not usually anxious for this to be seen. Should he overheat his melt, therefore, he immediately does what he can to prevent his delinquency from being observed, and as the best method which is generally available in a foundry is merely to place several cold iron bars into the melt, he does this, with the consequence that some of the iron is dissolved in the melt. In some cases the amount of iron introduced in this way is very excessive, and the writer has known hard spots in castings to consist simply of nodules of iron. The remedy is, of course, apparent, and the root of the trouble is to see that the smelter does not allow his melts to become overheated.

Small amounts of aluminum, manganese, and lead are not objectionable in 60/40 brass, but traces of arsenic must be rigorously excluded, and consequently the less expensive arsenical copper should not be used for making these alloys. Failures with this alloy are sometimes due to this fact not being known. 70/30 alloy, on the other hand, may be considerably improved by the addition of a trace of arsenic, and so some arsenical copper can be added to this alloy with advantage. With the exception of arsenic, however, 70/30 brass should be kept as pure as ever possible.

Copper-tin alloys are improved by the addition of small amounts of lead and arsenic, but should be free from aluminum, antimony, bismuth, iron, manganese, and phosphorus, except for phosphor-bronze. It is interesting to note, in this connection, that the metal lead is often thought to be a very undesirable impurity in copper-tin alloys of the gun-metal type, and even a certain Admiralty specification lays down that lead must not exceed a very small percentage in such alloys. Recent research has, however, proved that this popular idea is wrong, and it has been shown that some 0.5 per cent of

lead is highly beneficial to gunmetals. Its effect is to make the alloys stronger at moderately high temperatures—such as are met with in superheated steam locomotives and the like; and so it is clear that, apart from the superior properties of gunmetals containing lead, cheaper castings can be made, because virgin metals which contain a small amount of lead are cheaper than those which are free from this element.

It is well to note that when both 60/40 and 70/30 alloys are being made it is well worth the trouble involved to ensure that the resulting alloys are as close as possible to these figures, and not 3 per cent or 4 per cent of either element away from these percentages; the reason being that these alloys are most easily hot or cold worked when made to these figures, whereas, if the percentage of copper be reduced by 3 per cent, for example, then the alloys are both harder to work.

It is probably true that the most prolific cause of trouble and failures in a brass foundry is due to the overheating of the alloys when molten. The results of overheating are made manifest in many ways. In the first place, the analysis of the metal will be wrong, owing to the zinc which is lost by "slagging off," as it is called, and, moreover, bad castings are liable to be produced owing to pouring at too high a casting temperature. Similarly, badly blown metal may result, due to the metal containing too much of metallic oxides. It is also equally true that the trouble is a difficult one to overcome, because, although pyrometers may be successfully employed for large and difficult castings, their universal adoption is scarcely a truly practical proposition. In many instances, however, a good deal of the overheating can be prevented by carefully planning the sequence of operations before commencing the smelting. It frequently happens that the smelter is ready to cast his melt before the moulder is ready with his mould, or else there is not a crane available when wanted. These occurrences are, of course, easily obviated by more judicious planning of the work. An experienced and vigilant foreman is, perhaps, the best man for preventing overheating taking place, and if he knows the correct casting temperature for all the alloys he makes and can judge temperatures by eye with reasonable accuracy, he will be the means of saving many melts which would otherwise be scrapped, or at least severely harmed.

If, despite all precautions taken, overheating has occurred to a crucible of metal, the immediate application of a good flux will do much to remedy the harm done. Bronzes and gunmetals are less susceptible to the harmful effects of overheating than are brasses, which fact is, in part, due to the low percentage of zinc which they contain, and it is doubtless true that these alloys owe a certain amount of their popularity and great application to their ability to withstand, without much harm, a comparatively high degree of overheat.

The actual heating of metals in the crucible both prior to being molten and when molten is an important process, which usually receives too little attention. For some entirely mysterious reason it is often thought correct to heat alloys slowly prior to melting; but such practice is entirely wrong, and may be quite harmful, especially when the ordinary coke-furnace is employed for smelting. Most foundry cokes contain a fairly high percentage of sulphur, which combines with the oxygen in the air-blast to form sulphurous gases. As copper and most non-ferrous metals have a great affinity for sulphur there is danger of some of the sulphur combining with the metals to form metallic sulphides, which, being harmful substances, are to be avoided as far as possible. For this reason, therefore, non-ferrous metals should be heated as quickly as can be managed. Moreover, other oxidizing gases are formed in the furnace during smelting, which are also decidedly

harmful to the alloys, and so it is clear that rapid smelting will greatly reduce the possibility of contamination with these harmful gases. To guard further against this danger a copious covering of wood charcoal is very efficacious, and, indeed, charcoal is probably a good deal better than many of the proprietary fluxes on the market, for which many extravagant claims are made. The charcoal should be placed at the bottom of the empty crucible and the cold metals placed on top, so that when the metals melt, the charcoal will rise up through the molten metal and rid it of metallic oxides which may have been formed during melting.

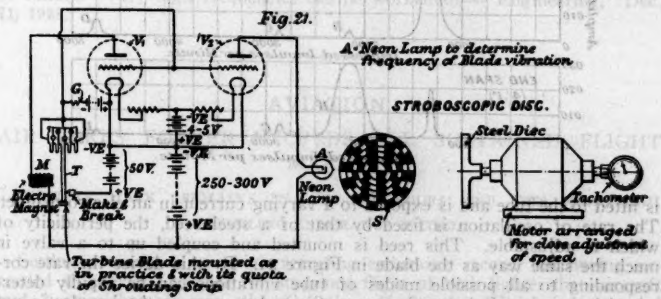
Although by no means exhaustive, the above few notes indicate some of the common faults which are repeatedly met with in foundries, which, if remedied, will result in the all-round improvement of the castings produced. —"Mechanical World and Engineering Record," Dec. 7, 1928.

RESEARCH WORK OF MESSRS. METROPOLITAN-VICKERS ELECTRICAL COMPANY, LIMITED.

Vibration is a frequent cause of trouble in high-speed machinery, and an interesting plant for studying such phenomena has been installed in the mechanical laboratory. The apparatus was originally intended simply for determining the natural periodicity of turbine blading.

The general arrangement is shown diagrammatically in Figure 21. The turbine blade under test, complete with its due proportioning of shrouding strip is represented at T. As it vibrates to and fro it opens and closes the make-and-break of an electric circuit, as indicated. It would have been possible to send the current in the blade circuit directly through the electro-magnet M, but this would have involved the breaking of a fairly heavy current, and the use of a more or less substantial contact piece, which, when mounted on the blade, would effect somewhat its natural periodicity. To avoid this, the apparatus is arranged so that but a small current goes through the blade, and at one point the blade circuit is coupled up to the grids of the two valves shown at V_1 and V_2. Any variation in the strength of the current

Fig. 21.

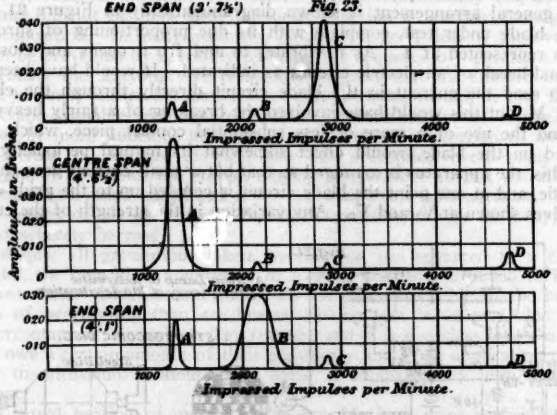


through the blade varies correspondingly the grid potential and hence the current through the anode circuit of the valves. It is, moreover, not necessary that the current through the blade circuit should be actually broken; it is sufficient if it merely varies in strength. In the one case the valve current goes through the electro-magnet M, and serves to keep the blade vibrating; the current from the other valve goes to the neon lamp shown. The light

given by this varies in synchronism with the blade vibration, and is thrown onto the stroboscopic disc shown at S. This is rotated by the motor on the right of the figure and the periodicity of the vibrating blade is determined by adjusting the motor speed until one of the rings of alternating black and white spaces appears stationary.

By the addition of other valves and accessories, the apparatus has been adapted to other purposes, such as the study of condenser tube vibration, and in a still later development to fatigue testing.

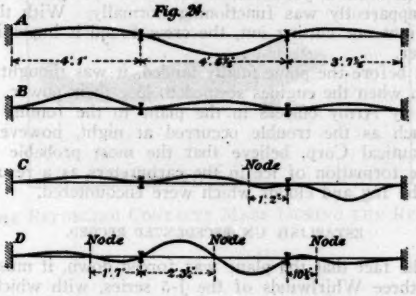
To obtain the high water speeds required for efficient heat transfer in surface condensers, it is necessary to employ either long condensers or multiple water passes, and in general the former alternative has been preferred. This has, howver, led not infrequently to the failure of tubes by vibration, due to some synchronism between some of the natural periodicities of a tube and that of some of the power station plant. As a tube may vibrate in a number of ways, the calculation of these natural periodicities is troublesome, and it may be added that experience shows that it is not possible accurately to forecast all cases, due to the variation in degree of freedom at the sagging plates. Hence at Trafford Park the plan has been adopted of determining these periodicities by direct experiment. To this end the tube is mounted exactly as it is to be in the condenser. A light Stalloy armature



is fitted to the tube and is exposed to a varying current in an electro-magnet. The rate of oscillation is fixed by that of a steel reed, the periodicity of which is adjustable. This reed is mounted and coupled up to a valve in much the same way as the blade in Figure 21. By this device the rate corresponding to all possible modes of tube vibrations can be rapidly determined by means of the stroboscope. Since, however, as the impulse is not sinusoidal, tube vibration can be maintained by sub-multiples of the real periodicities, a second neon lamp is provided, the current through which is governed by the oscillations of the tube. This can also be used independently to illuminate the stroboscope and shows at once whether the periodicity of the magnet current is or is not some octave of that of the tube. The amplitude of vibration is also measured by suitable micrometers.

A number of interesting results are plotted in Figure 23. It will be seen that the important natural periodicities varied much from span to span. In the case of the end spans the most violent oscillations occurred in the one case at a periodicity of about 2800 per minute, whilst at the other end the worst periodicity was about 700 less. Moreover, in the latter case the tuning was far from sharp. There was resonance over a range of more than 200 vibrations. The shapes taken by the tube corresponding to the periodicities lettered A, B, C and D on Figure 23 are shown in Figure 24.

Fig. 24.



As already noted, the apparatus has also been adapted to fatigue testing, and, as in the frequency test, the specimens are maintained in vibration by an electro-magnet, the periodicity of the current through which is controlled by the natural frequency of the specimens themselves. A mirror is fixed to the specimen and a ray of light after reflection from the mirror describes a line on a screen. The path described is a straight line until incipient failure, when in general it becomes an open curve and indicates the commencement of failure. Very high frequencies can be worked to.—"Engineering," Dec. 21, 1928.

AVIATION.

AIR CORPS FOKKER EXCEEDS ALL SUSTAINED FLIGHT MARKS.

"QUESTION MARK" REMAINS IN AIR 150 HOURS AND SETS NEW HIGH REFUELING ENDURANCE RECORD.

Setting not only a new high refueling endurance record, but having exceeded all previous records for sustained flight of both lighter-than-aircraft and heavier-than-aircraft, the *Question Mark*, the *Whirlwind* powered Fokker transport monoplane of the Army Air Corps, was forced down at the Metropolitan Airport, Los Angeles, Monday, January 7, at 2:07:01 P. M., after having remained in the air for 150 hours, 40 minutes, 15 seconds. To those on the field, it was apparent that a landing might be necessary almost an hour before the wheels of the Fokker touched the ground. The *Question Mark* had been flying at a height of from 3000 to 4000 feet, but it

gradually lost altitude and was finally forced to dump its supply of gasoline and to land. This was necessitated because of a partial failure of the engines, which caused the plane to settle.

ATTEMPT TO MAKE ADJUSTMENTS.

The left engine was missing badly "Aviation" was reliably informed. The switch was cut, and the mechanic was sent out on the cat walk in an effort to make the necessary adjustments. At the same time, the right engine, which was throwing oil from a yet undetermined source, began to cut out. The center engine apparently was functioning normally. With the left engine dead and the right one cutting out, the crew found it impossible to remain in the air longer.

Thirty hours before the plane finally landed, it was thought that it might be forced down when the engines seemed to lose their power. This at first was attributed by Army officers in the plane to the fouling of the spark plugs. Inasmuch as the trouble occurred at night, however, experts of Wright Aeronautical Corp. believe that the most probable cause of the trouble was the formation of ice in the carbureters as a result of the low temperatures, the fog and clouds which were encountered.

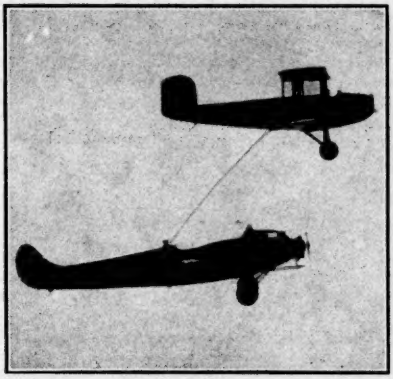
ESTABLISH UNPRECEDENTED RECORD.

In spite of the fact that the plane was forced down, it must be borne in mind that the three Whirlwinds of the J-5 series, with which the Fokker was powered, have established an unprecedented record. Under ordinary conditions, which permit making minor adjustments from time to time, these engines should operate for a period of 400 hours between overhauls. The fact that the three Whirlwinds operated continuously for more than 150 hours without adjustments of any kind is a remarkable record. The flying time of the *Question Mark* during its endurance test more than exceeds an average month's operating time for the planes and engines used in carrying mail, it is said.

Army officers at the field were overjoyed with the performance of the Fokker. In addition to setting a new refueling endurance record, they agreed that the operation of refueling airplanes in flight has been definitely established as practicable. Aside from the military advantages that will result, the ability to refuel planes in the air will mean much to commercial aviation, they said. In commenting upon this, they cited the points that planes will now be able to make more rapid flights across the country, greater cargoes may be carried, that increased flying hours for both planes and engines may be expected, and that the danger of robbery for planes carrying valuables will be minimized.

In its flight, the *Question Mark* is estimated to have flown approximately 11,000 miles. While it actually maintained a speed of approximately 70 M.P.H., it has been estimated official records of the N. A. A. may show its speed to be only about 17½ M.P.H. This is because the greater portion of the flight was made near the Metropolitan Airport and not over the official course between it and Rockwell Field. Weather conditions and the slight trouble that earlier was experienced with the engines prevented this.

The *Question Mark* took off on its record-breaking flight from the Metropolitan Airport the morning of January 1, with Capt. Ira C. Eaker, well-known cross-country pilot of the Army Air Corps, at the controls. Besides Captain Eaker, the crew consisted of Maj. Carl Spatz, flight commander; Lieut. Elwood R. Quesada and Lieut. Harry A. Halverson, co-pilots; and Staff Sergt. Roy W. Hooe, mechanic.



One of the Refueling Contacts Made During the Record Flight.

The Newly-Developed Mercedes 12-Cylinder Power Plant.

Less than 100 gallons of gasoline, sufficient for a flight of only about three hours, were in the wing tanks of the Fokker when it took off. As a result, the first of the refueling operations was performed a little less than an hour later over Lankershim, which is near the field. Lieut. Odas Moon, piloting one of the Douglas transports equipped for the purpose, gained a position above the *Question Mark,* which was flying at an altitude of about 2800 feet. A 50-foot hose was let down and 100 gallons of fuel were transferred during the eight minutes that contact was maintained, even though the altitude of both planes was reduced about 800 feet in seeking better air conditions.

REFUELS OVER NORTH ISLAND.

The second refueling was accomplished over Rockwell Field, North Island, San Diego. On this occasion, in addition to gasoline, the plane received seven five-gallon cans of lubricating oil for the engines. A turkey dinner prepared by the women of a church located near the airport, was also taken aboard, so that on the flight north again to Los Angeles the crew ate its New Year's dinner.

The plans for refueling as prepared by Major Spatz called for the delivery of fuel at 8 A. M., 4 P. M., and at midnight. The first night fueling operation was described by Captain Eaker in the log of the plane as being "easy," according to a copy of it that was dropped at the Metropolitan Airport. However, Major Spatz who was handling the hose reported that his face and eyes were showered with gasoline when the hose was released. The result was not serious, but called for the use of the first-aid kit carried in the plane. Besides the gasoline and oil, warm food for the crew of the Fokker was transferred regularly at the time of the morning and afternoon contacts.

At 8:45 P. M., the second day of the flight, the Question Mark passed the only previous American refueling endurance record of 37 hours, 15 minutes, 40 seconds, established by Lieuts. Lowell Smith and Paul Richter in August, 1923. The next day the plane broke the record established by two Belgian fliers in June, 1928, when, early in the evening, the Fokker had been in the air over 61 hours. Shortly after midnight, it had been in the air 66 hours, 25 minutes, exceeding the world's endurance record established in July, 1928, by the German pilots, Risticz and Zimmerman, with their Junkers monoplane. The record was not broken, though, for the flight of the Germans was made without refueling.

Having passed all the existing marks for heavier-than-aircraft, the Army fliers set out to beat those set by lighter-than-aircraft. On Sunday morning, January 6, they had accomplished this by passing the 118 hours, 41 minutes mark reached unofficially by the dirigible *Dixmude,* on the longest flight from the standpoint of endurance ever recorded for lighter-than-aircraft. The *Question Mark* did not stop at this, and Sunday at 9:26.46 P. M. it had been aloft continuously for 134 hours.—"Aviation," January 12, 1929.

CONSOLIDATED PATROL PLANE.

An experimental type of flying boat, the *XPY-1,* constructed by the Consolidated Aircraft Corporation of Buffalo, N. Y., is now at the Naval Air Station, Anacostia, D. C., for tests and acceptance trials.

This seaplane is of a monoplane type with metal hull. It has two 450 H.P. Pratt and Whitney Wasp engines with emplacement on top of the wing for a third engine which the designers believe will increase the speed 15 miles

an hour. Its length is approximately 62 feet with a wing span of 100 feet, and it has two Richardson type wing tip pontoons. It has a high speed of 120 M.P.H. and a cruising speed of 100 M.P.H.

The contract for this plane was awarded on February 28, 1928, and the plane was flown for the first time at the Naval Air Station, Anacostia, on January 10 with Lieut. A. W. Gorton, U. S. N. pilot, and Mr. J. M. Laddon, chief engineer, Consolidated Aircraft Corporation, observer. The plane was flown again on Friday, January 11, and is now being tried out by the Navy's test board at Anacostia. This is the first large flying boat directly convertible into a commercial type transport. It has a compartment 60 feet long which will hold 32 passengers.

MERCEDES-BENZ CO. OFFERS NEW ENGINE.

Berlin, Germany.—A new 12-cylinder aircraft engine of the water-cooled "vee" type is now being offered by the Mercedes-Benz Co. This power plant has an output of 800 to 1000 H. P. at 1500-1700 R.P.M. The bore is 5.44 inches and the stroke 8.19 inches, giving a piston displacement of 3285 cubic inches. The weight of the power plant complete, including equipment and reduction gear, is 1800 pounds. The fuel consumption is 220 grams (.481 pound) per H.P. hour, and the oil consumption 10 grams (.021 pound) per H.P. hour.

Each cylinder has two inlet and two exhaust valves and all parts, including rocker arm mechanism and concentric valve springs, are contained in the oil-tight casing of the cam shafts. Crankshaft and connecting rods are mounted in roller bearings.

Four carburetors are used and are placed between the cylinder banks and fed by two fuel pumps. The turbo-compressor is located at the rear end of the engine. A water pump is provided for each bank of cylinders and one pressure and two scavenger pumps are used in the lubrication system.—"Aviation," Dec. 8, 1928.

BOOK REVIEWS.

AMERICA'S PART, BY HENRY J. REILLY, BRIGADIER GENERAL, O. R. C.

In looking back at the Great War and the part America played in it, the tendency seems to be universal to remember with pride the tremendous efforts made in this country to make up for the condition of unpreparedness in which the country found itself upon the declaration of war. There always come to mind the vast sums of money advanced to the Allies, the food, munitions and other supplies sent abroad, the building of a great number of cargo carrying vessels to carry these supplies abroad and the raising of immense armies by conscription. In other words, our record of help rests principally upon a universal and open handed outpouring of material, and not upon the fighting of Americans abroad.

We all know that our men did fighting and in all our minds, as well as in the minds of those who were in these battles, there will always remain such names as Belleau Wood, Chateau Thierry and the Marne. However, it is not believed that the average American has any real idea as to what part the Americans as a whole took in the campaign which led to the final victory, nor what weight our armies threw in the scales to overbalance them finally on the side of the Allies. Certainly the impression gained from foreign papers generally is that the Americans did but little fighting and that our part in the war consisted principally in supplying the money and material supplies needed by the Allies.

In "America's Part" General Reilly gives in detail and for the first time in complete and understandable form a full and most interesting description of the part actually played by this country and the American soldiers on the fighting line from the declaration of war until the Armistice. In this book he brings out the insistence of General Pershing from the first that America must have

an army of its own on the front, an army composed of American men commanded by American officers under the Supreme Commander of the Allied Armies, the formation and development of this army, and its notable and important part in bringing about final victory. He shows, too, how the American, as a fighting man, early proved his mettle and his worthiness to fight by the side of the war hardened soldiers of the Allies.

No one better than General Reilly could have been chosen to write such a book. His qualifications are well set forth by General Harbord in the Preface. General Reilly is a graduate of West Point and early interested himself in the organization and tactics of foreign armies. On leave he followed the Russo-Japanese War. Later he resigned from the Army to become a war correspondent and followed wars in China, Mexico, and Europe. Returning to the Army with our entry into the war he first commanded a light artillery regiment and later an infantry brigade of the 42d, Rainbow, Division. In these capacities he participated in every combat in which the Rainbow Division was engaged.

With this background he speaks in his book from first hand knowledge and he speaks with the experience and the ability of a trained war correspondent. What he has to say is most interesting and thrilling. Every American who would learn what part America played in the fighting which actually won the war, and the strategy of the last moves which led up to the end, will find in this book a clear exposition of the subject and a cause for great pride in his country and her fighting men.

COMMANDER H. S. HOWARD (CC), U. S. N.

POCKETBOOK FOR MARINE AND SEA-GOING ENGINEERS (TASCHENBUCH FUR SCHIFFS INGENIEURE AND SEEMASCHINISTEN), BY E. LUDWIG, 4th Edition, BY R. OLDENBURG, Muenchen, 588 pages, 495 figures. Price, RM-12 (linen binding).

Contents as follows: I Mathematical Tables; II Mathematics, Mechanics, Physics, Strength of Materials; III Propelling Machinery, Steam Engines, Turbines, Internal Combustion Engines;

IV Steam Boilers; V Auxiliary Machinery; VI Pipe Systems; VII Ships Auxiliaries; VIII Electrical Installation on Board; IX Instruments and Measurements; X Shipbuilding—Sail and Propelled Ships; XI Seamanship and Allied Subjects; XII Laws and Regulations; XIII Miscellaneous Tables.

This is the fourth edition of this pocketbook, formerly edited by the well known German marine engineer Dr. G. Bauer, who was also consulted on the make up of this edition. Several others have also contributed chapters on their special fields. The book was brought up to date and those who read German can find much useful information on all kinds of questions, confronting a marine engineer. The descriptive part of propelling machinery is limited to engines of German manufacture, however.

E. C. MAGDEBURGER.

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25 YEARS OF TURBINE BUILDING, BY A. E. G., in German, 132 pages, 191 figures. Price, RM-5. Published by V. D. I., Berlin N. W. 7 1928.

To commemorate the fact that the A. E. G. Co., 25 years ago began building steam turbines, a booklet has been published by V. D. I. which reviews the development and the present status of turbine building by this famous German organization. Much preliminary work including fundamental inventions resulted in the building and trials of the original and unsuccessful types of turbines. On this foundation, however, was later developed a practically satisfactory type which since was manufactured in large numbers. The demand for larger capacities and better efficiencies and the desirability to combine power and heat development and distribution as well as the tendency to use turbines for direct drive of ships and other machinery in addition to electric generators—all of these are responsible for the multiplicity of modern turbine types. Elaborate figures show the effect of this development upon the electrical industry.

The anniversary booklet shows further a complete picture of the modern turbine building industry in all its applications. Begin-

ning with the cycle of operation and the constructional details all types of turbines are discussed from the smallest sizes up to turbines of maximum capacity. Electric generators, rotary air compressors and auxiliaries are also well covered. Special types for highest pressures, stage heating, intermediate tapping, and for operation from Ruths accumulators, driving several machines of different speeds and various other applications of turbines are shown.

The equipment of the shops and apparatus used for test of turbines and to carry on the research necessary for further development of the art are also dealt with adequately.

This publication with its mass of illustrations is not only an anniversary booklet but an important record of modern industrial development

E. C. MAGDEBURGER.

STANDARDS AND STANDARDIZATION, BY NORMAN F. HARRIMAN. Published by McGraw-Hill Book Co., Inc., New York.

A concise and well-arranged discussion of a subject which is becoming steadily a matter of greater importance to the engineer and technologist. Written by an acknowledged master of the subject it will find much active use on the technical book-shelf. The author has kept clearly in mind the acrimony which so readily develops when standardization is discussed, and although he is an ardent and enthusiastic advocate, never fails to point out its limitations, and the dangers of over-standardization.

He traces its early history, the development of standards, and the present need of standardization as the great weapon of industry today in its battle against waste.

Two sections of the book make it exceptionally desirable to have about as a work of reference. The chapters dealing with the derivation, construction, and present status of our physical standards will be especially valuable to engineers, and it is doubtful whether there has ever been assembled before as complete and

authoritative discussion of the organization and work of the great International and National standardizing agencies, and their interrelations, as the author has given.

In his conclusion, Mr. Harriman ventures to predict that we are on the verge of a second great industrial revolution where mass production and mass distribution will figure as never before, and his major premise is that the great standardization movement which pushes us today is the direct means to that end.

LIEUT. COMDR. R. W. PAINE, U. S. N.

ASSOCIATION NOTES.

ELECTION OF OFFICERS.

Votes cast for officers of the Society for 1929 were counted at a meeting of the Council held on December 28, 1928, and the following declared elected:

President:
Rear Admiral H. E. Yarnell, U. S. Navy

Secretary-Treasurer:
Commander H. T. Smith, U. S. Navy

Council:
Rear Admiral C. W. Dyson, U. S. Navy, Retired
Captain I. E. Bass, U. S. Navy
Captain O. L. Cox, U. S. Navy
Captain R. B. Adams, U. S. Coast Guard
Commander H. S. Howard (CC), U. S. Navy
Mr. H. M. Southgate
Mr. J. F. Metten

AMENDMENTS TO BY-LAWS.

Ballots were counted on proposed amendments to our By-laws and all were declared adopted. These were:

(1) To provide for dropping of members in arrears for dues for two years.

(2) To permit Civil Members to vote.

(3) To provide a committee to present nominations for offices at the Annual Meeting.

PRIZE ESSAY.

By ballot, the Council of the Society decided that no article submitted during the year 1928 was of a standard warranting the award of a prize.

ANNUAL BANQUET.

The annual banquet of the Society was held at the Willard Hotel, Washington, D. C., on the evening of January 18, 1929. About 250 were in attendance and the occasion proved a thoroughly enjoyable one. Details are given elsewhere in this number. The committee in charge consisted of Captain Carlos Bean, U. S. N.; Commander C. A. Jones, U. S. N.; Commander H. T. Smith, U. S. N.; Commander H. S. Howard (CC), U. S. N., and Mr. B. P. Lamberton.

FINANCIAL STATEMENTS.

Following are the financial statements for the year 1928:

STATEMENT OF INCOME AND EXPENDITURES.

Expenditures.

Publication:			
Printing	$7,252.83		
Engraving	1,091.73		
Manuscript	895.00		
Drafting	6.00		
Postage	132.49		
Commission	226.44	$9,604.49	
Salaries		2,650.00	
General Expense		400.86	
Current Profit and Loss		397.39	
Banquet, 1928		89.84	$13,142.58

Income.

Publication:			
Dues	$5,032.50		
Subscriptions	2,766.92		
Sales	249.75		
Advertisements	3,217.00		
Exchange	1.56	$12,167.73	
Interest on Investments		904.82	13,072.55
Net Loss			$70.03

BALANCE STATEMENT.

Assets January 1, 1928		$18,972.19
Assets December 31, 1928:		
Cash in Bank		$3,482.60
Accounts Receivable:		
Advertisements	$998.25	
Dues	642.00	
Sales	54.91	
Subscriptions	69.60	
Certified check deposited in lieu of bond for contract	276.25	
Miscellaneous	3.60	2,044.61
Investments (all bonds):		
Armour & Co. of Delaware	$887.50	
Army and Navy Club	1,000.00	
Bethlehem Steel Co.	957.50	
Canadian Northern Ry.	1,115.00	
Hocking Valley R. R.	1,682.50	
International Mercantile Marine	795.00	
New York Steam Corp.	927.50	
Ohio Power Co.	860.00	
Penna. Power and Light Co.	882.50	
Swift and Company	917.50	
Washington Ry. & Elec. Co.	4,230.00	14,255.00
Furniture		182.00
		$19,964.21
Liabilities:		
Dues paid in Advance	$137.00	
Subscriptions paid in Advance	810.05	
Banquet 1929 subscriptions	115.00	1,062.05
Net Assets December 31, 1928		18,902.16
Net Loss		$70.03

These accounts will be referred to an audit committee in the usual manner.

MEMBERSHIP.

The following members have joined the Society since the publication of the November, 1928 JOURNAL:

NAVAL.

Brown, Walter E., Lieutenant Commander, U. S. N.
Burgy, W. C., 24 South Maple Ave., Webster Groves, Mo.
Cunneen, Frank J., 1327 Ingraham St., N. W., Washington, D. C.
Fulton, Garland, Commander (CC), U. S. N.
Gilmore, Morris D., Lieutenant Commander, U. S. N.
Hawkins, George C., Lieutenant, U. S. N.
Hoeffel, Kenneth M., Lieutenant, U. S. N.
Kidder, Edmund J., Lieutenant, U. S. N.
Paine, Roger W., Commander, U. S. N.
Pomeroy, Joseph G., Lieutenant, U. S. N.
Smith, Hayden H., Lieutenant, U. S. N.
Thompson, Terry B., Lieutenant Commander, U. S. N.
Thompson, Webster M., Lieutenant Commander, U. S. N.
Whitlock, E. J., 40 Rector St., New York, N. Y.
Wright, Percy T., Commander, U. S. N.

CIVIL.

Hanly, F. F., 323 Munsey Building, Washington, D. C.
Jackman, Irving W., 88 Bergen St., Westwood, N. J.
Lang, Emil H., Erie Forge Co., Erie, Pa.
Lunsford, Jesse B., 1 Beech St., Clarendon, Va.
Rathman, Gilbert, Chief Engineer, Quimby Pump Co., 340 Thomas St., Newark, N. J.
Spanner, E. E., 6 Billiter Square, Billiter St., London, E. C. 3, England.
Stout, G. W. J., V.-P. and Gen. Supt., Erie Forge Co., Erie, Pa.

ASSOCIATE.

Horton, W. C., Engineer Commander Royal British Navy, British Embassy, Washington, D. C.

ADDRESSES.

Please do not fail to keep the Secretary advised of your address in order that each number of your JOURNAL may reach you promptly. Naval Members should bear in mind that because of

the new practice of the Department in issuing orders at times far in advance of date of taking effect, it is impracticable to make use of the Daily Orders to Officers in connection with addresses.

JOURNALS FOR SALE.

A member of the Society offers for sale twelve volumes of the JOURNAL, 1917 to 1928, unbound. Address William E. Volz, M.E., care American Society of Naval Engineers, Navy Department, Washington, D. C.